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OF

The Institution of Engineers and Shipbuilders

IN SCOTLAND

(INCORPORATED).

VOLUME XXXVIII.

THIRTY-EIGHTH SESSION,
1894-95.

EDITED BY THE SECRETARY.

GLASGOW:
PRINTED FOR THE INSTITUTION BY
WILLIAM ASHER, 80 GORDON STREET.
1895.

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Sci 1490.155

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Engin. Astrophys.

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To Mr Alexander Morton, for his paper on "Rotatory and Re-action Engines."

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INSTITUTION
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ENGINEERS AND SHIPBUILDERS
IN SCOTLAND.
(INCORPORATED.)

THIRTY-EIGHTH SESSION, 1894-95.

Introductory Address.

By Mr JOHN INGLIS, President.

Read 23rd October, 1894.

GENTLEMEN—

At this year's session of the British Association, the learned President of Section G. recorded the opinion that Presidential addresses were in the nature of them almost immoral, and fit only to be abolished.

It is always delightful to find one's own crude and unshapen thoughts expressed with vigour and precision by a master, and, in all my recent reading, nothing has more nearly attained to the ideal of the word in season, meeting my eye, as it did, just as I had awakened to the near approach of the thirty-eighth series of the meetings of this Institution.

But, though fortified in no small degree by the opinion quoted above, I have scarcely courage sufficient to introduce, all at once, so startling a change into our programme as the entire suppression of

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the remarks which, in accordance with usage, are expected from the Chair at the opening of the Session; and I propose to effect a sort of compromise by being somewhat brief on the present occasion, and in this also I follow the custom of most of my predecessors in their second year of office.

The Institution, I am glad to say, continues still in a flourishing condition, the numbers on the roll steadily increase, and there is no falling off in the interest of the members in its proceedings.

Our short honorary list has been recently adorned by the name of the Director of Naval Construction, Dr W. H. White, who worthily represents the profession of Naval Architecture.

On the other hand, the name of the illustrious Helmholtz disappears from among those of our honorary members, his death having taken place last month; and in December, 1893, Professor John Tyndall's decease was hastened by misadventure.

Our obituary also contains the name of a Past President and most distinguished engineer, Mr James Reid, whose busy life was suddenly closed during a short and well-earned holiday. Mr Reid's addresses, while he held office, are among the most important of the contributions to our Transactions, and display an exhaustive knowledge of the history of that branch of engineering wherein he made his reputation.

The deceased Members and Associates are Mr David Henderson, equally well known and esteemed as shipowner and shipbuilder; Sir Archibald Orr Ewing, Mr John Morgan, and Mr William M'Ivor Morrison.

The Institution work of last session may fairly be considered of much interest and value. A timely paper by Professor Biles, on "The Strength of Large Ships," is apparently, from its tenor, the first instalment of a lengthy contribution on this subject; and, doubtless, we may confidently expect, although it is not yet announced, that the learned Professor will follow his very complete statement of the strains to which large ships may be liable, by an equally complete exposition of the manner in which these strains

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are to be met, showing the most advantageous disposition of material in the structure.

The elaborate paper by Mr Arnot evoked one of the liveliest discussions ever heard within these walls, and one which has, for some time at least, delivered us from the reproach, often levelled at similar societies, of being conducted on the principle of mutual admiration.

To the authors of some of the shorter papers, and to those who may have material by them for other short papers, I desire to offer a word of encouragement. The importance of a new invention, or mechanical arrangement, is hardly to be estimated by the number of words required to describe it. An epoch-making invention is indeed a rarity, and the birth of Minerva is in no way typical of the appearance of those contrivances which have wrought such mighty changes in the industrial world. There is probably no machine of any consequence which is not the sum of many successive increments of invention or discovery, and the product of the ability and efforts of many workers.

It is on evidence that the ingenious spinning machinery, now in common use, is a compound of about eight hundred different inventions. How minute some of them must have been, and yet how indispensable!

Precisely because the progress of invention is, as a rule, made by short steps, and in obedience to necessity, which is the mother of it, the most notable inventors have, as a rule, not been "scientific men," that is to say, men exclusively engaged in scientific research, as distinguished from those mainly occupied with commerce or manufactures. (A brilliant exception to this rule will at once occur to all Glasgow men, but there is only one Lord Kelvin.) The continual desire to strengthen the weak parts of an industrial process directs the minds of many eager searchers to contrivance, until to one a fortunate solution presents itself, and invention is carried forward another pace. Therefore, the diffidence that would make us hesitate to bring forward improvements because they do not appear sufficiently imposing, or because we may not be able to clothe our

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thoughts in words at once elegant and exact, is out of place among the members of this Institution. It must not be forgotten that one of our objects is discussion, and the salient points of a communication are more readily seized when they are few.

I have, though not without an effort, resisted the temptation to provide myself with a subject for this evening out of some of the remarks on ocean steamers made when I had the honour of addressing you twelve months ago.

Adverse criticism is always stimulating, and I am far from complaining of it; but it was surprising to find what I introduced as a mere reference, or illustration, taken as the main subject of discourse, and an attempt to do justice to the past treated as a discouragement of progress in the future.

We cannot but admire the enterprise and sagacity shown by the moving spirits of the great shipowning companies at home and abroad, and we must admit that it is not by a timid and shrinking policy that great industrial revolutions are carried out. It is an axiom, that he who never makes a failure never makes anything; and, in like manner, the cautious seeker after safe investments is not, as a rule, the pioneer of civilisation, or the organiser of new outlets for industry.

But while we look with pride at our mercantile marine, its prodigious capacity for transport, the excellence of its construction, and the skill with which its movements are directed, there is no irreverence in watching carefully for the appearance of any policy which may endanger its prosperity. The profitableness of navigation is therefore a legitimate subject of inquiry to the scientific shipbuilder, whose methods may very possibly yield results not easily obtained by the unaided commercial expert.

It is but a few weeks ago that one of the most able of administrators of shipowning enterprise publicly admitted that ships, of the type of the most recent addition to his fleet, could not be made commercially successful without the aid of a Post Office subsidy for mail carrying. It would be presumptuous to claim Sir Thomas

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Sutherland as a convert, or even to suppose that his mind on the subject had only been recently made up. I merely quote his dictum as an emphatic termination to the existence of any difference of opinion on this question which may have hitherto survived.

The question of the profitableness, or, as many would prefer to say, the unprofitableness, of shipping in general, is but part of the larger question, the condition of the world's trade; and for that depression which is at present all but world-wide, there are many who consider that no small part of the responsibility lies on the makers of all kinds of machines for the saving of labour. According to one of the most prominent of continental steamship directors, "the engineer has gotten the better of the man of business;" and if this be true, and of general application, it is surely a very serious reflection for us who hope to earn a living by continuing to furnish labour-saving appliances.

All the pessimists are, however, not of one mind, and various are the causes assigned for the present slackness of demand for our wares, and the abasement of ocean freights. Monometallism, labour disturbances, the private ownership of land and minerals, as well as over-production, are favourite suggestions of those disposed to take sombre views of the future. The optimist, on the other hand, points to recurrences of periods of good and bad trade, and talks of cycles and the swing of the pendulum; but, while it is pleasant to believe in him, we cannot altogether disregard the exceptional position among the ages of the century now nearing its close.

It has seen the application, on a great scale, of steam to what are still called *manu*factures, and to locomotion, the peopling by civilised races of America, Australasia, and much of Africa, the spread and consolidation of our empire in India, the opening to commerce of China and Japan, and the shortening of trade routes to the East by means of the Suez Canal. That is to say, it has been a time of extraordinary increase of activity in production, of simultaneous increase of demand for commodities, and of the means of transporting these to great distances at small cost.

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Another so momentous a change in the aspect of the world, as the last three generations have witnessed, is hardly within the bounds of probability. Therefore, without being either alarmist or pessimist, one may feel some anxiety as to the future of those who depend on the continued absorption of the products of modern industrial appliances, and may decline to be quieted by the assurance that history repeats itself, and that what has been will be.

As concerns the use of this or that metal in coinage, it is difficult to see how the fixing by law of the relative values in exchange of any two or more substances could bring about a general increase of wealth and prosperity; and, having seen periods of good and bad trade, without any coincident alterations in the standards, I am of those who have no faith whatever in bi-metallism as a cure for the ills from which commerce now suffers.

The disastrous effects of labour troubles are too obvious to require demonstration, and the guilt of those who, from ignorance, prejudice, or self-interest, foment disputes in the labour market, is none the less manifest and heinous because it is not recognised by the law. But, as the abolition of all suspensions of industry by labour wars would result in still greater production, those who strive to promote industrial peace must still reckon with those who maintain that there is too much activity in production already.

I hasten to allay the uneasiness you may possibly feel as to any intention of mine to discuss the systems of land tenure in this country, or their effects upon the home or foreign trade. I shall say no more than that I believe the usages connected with the occupation of land have yet to be completely adapted to the new environment, of which modern mechanical appliances are mainly the cause, and that this adaptation, like all radical changes, will probably continue to be attended by much suffering to individuals.

The complaint of over-production is by no means easy to dispose

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of. It formed the subject of one of Carlyle's eloquent chapters half-a century ago, when the sum-total of production was a mere fraction of what it is to-day; and, indeed, it is not difficult to be both eloquent and impressive about over-stocked warehouses, and the destitution which surrounds them; about "the frightful overplus of shirts," and "the millions of bare backs." It is all very well to take refuge in epigram, and say that over-production is only a synonym for bad distribution, and when the blocks in the channels of distribution are removed all will be well; but the satisfaction to be thus derived is by no means substantial or enduring.

Not that there is any lack of proposals for the amelioration of the world, in regard to the distribution of its goods. Dynamite, as an agent for the regeneration of society, has its advocates, and scarcely more reasonable are the leather-lunged preachers of the pillage of the rich, with or without legislative sanction—these we may leave to the police; but when one of the loudest of the orators from Hyde Park platforms speaks of Labour as crucified between two thieves—Capital and Machinery—our attention is arrested by this assailing of our craft.

We can imagine the applause with which this sounding figure of speech would be received by even the respectable portion of the listeners, who doubtless, in a vague way, felt themselves flattered by being compared with the central figure in the great tragedy; but it was probably far from the speaker's intention to convey to his audience that when Labour suffers, Capital and Machinery suffer with it. Such as he have usually no compassion to spare, except for those with whom they are bound, *ex officio*, to sympathise. What he wished to enforce was that the condition of Labour, that is of the bulk of the people, was made not better, but worse, by the presence of Capital and Machinery. And this is the argument, not only of hysterical members for Labour, but also of sober and studious economists, who, if they were to push their theories to a logical conclusion, would deprive us of all implements and devices, by the aid of which we have, as a race, emerged from the savage state of our remote ancestors.

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"Arms and the man," says Carlyle, "is no longer the epic of this world, tools and the man has taken its place;" and can we believe that the perfecting of tools, which is the engineer's business, is pernicious to the general interest?

The truth about the matter I believe to be that the condition of things, which we agree to call over-production or depression of trade, is not primarily due to machinery, but, in a great measure, to the reckless borrowing by impecunious states, communities, and associations, encouraged by the imprudence of financiers, and the credulity of the public as to the powers of Governments and other debtors to fulfil their obligations. The abnormal and unwarranted demand for goods from those put in easy possession of borrowed funds is rapidly met by the setting in motion of modern machinery —itself partly brought into existence by the necessity temporarily created. High prices become the rule, until the inevitable glut takes place, when there follows the revulsion to prices which are unremunerative. The fall in values is perhaps increased in rapidity by machinery, but the unwholesome stimulus is not immediately traceable to mechanical appliances.

Apart from commercial crises, probably the most potent effect on price levels and the condition of trade is produced, not by the strife which is supposed to exist of necessity between labour and capital, but by the constant struggle of holders of capital with each other in the quest of remunerative employment for wealth, mainly created within recent times by machine production. This has caused the invasion of every department of industry by groups of persons without skill or experience, and possessed only of money or credit, or, it may be, of aristocratic lineage.

The competition of these with each other frequently results in the redistribution of their wealth among the community, in the form of the increased wages and reduced prices, with which we are familiar, and against which we are sometimes disposed to rebel.

The ever-extending use of labour-saving devices in workshops and factories, whose owners have command of large capital, gives some

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plausibility to the contention that machinery is much to blame for trade depression, especially if the displacement of labour is not at once, and obviously, made up for by the cheapening of products, and greater facilities for transport stimulating demand; but wider views would probably disclose that the balance is speedily restored.

It is interesting, and indeed necessary, for us to inquire what becomes, after all, of the displaced labour, and if there is any visible limit to the substitution of machinery for handicraft. If we avail ourselves of the examinations of the census returns, by Messrs Booth, Hobson & Marshall, we shall find, for example, that while the output of textile goods has enormously increased, the proportion of labour employed in their production has continuously diminished.

Again, while rural population has declined but little, the number of persons engaged in agricultural labour has largely declined, and this falling off began long before the comparatively recent fall in rents, and what is recognised as the decay of agriculture in this country.

The additions to our working population have, therefore, not been absorbed in due proportion by these two great departments of industry, but are to be found, according to the authorities named above, engaged in shop-keeping, commercial pursuits, in the work of transport, and the industries subsidiary thereto. Among these, one of the most important is shipbuilding, which afforded employment to 40 per cent. more persons in 1891 than in 1881. Those engaged in the making of machines, tools, and instruments during the decade increased 28 per cent. These have been the most progressive of our industries, and indicate the extraordinary growth of transport and machine making as modern outlets for labour.

The extension of railways has not prevented the increase of traffic by road, as the employment of labour in the making and repairing of roads, in the conducting of road traffic, in the building of carriages and waggons, and the making of harness, shows considerable increase.

Coal miners have increased in numbers—35 per cent. in ten years—but the output of coal is only 20 per cent. greater, indicating

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the serious interruptions to which this industry seems peculiarly liable.

Notable increase is also shown by the professions, clerical, legal, and medical—indeed, on the authority of the Chancellor of the Exchequer, the incomes of physicians and lawyers together exceed the whole of the profits of the cotton and coal industries.

There is great increase of the teaching guild, and of the numbers of painters, actors, and musicians. These have been set free, by the action of machinery, from the necessity of manual labour. Machinery, therefore, indirectly encourages the study of theology and science, the cultivation of the fine arts, and the graceful acquirements of those who minister to our recreation. Even the army, navy, and police grow more quickly in numbers than the population as a whole. Our protection is thus made more adequate by the art of the mechanical engineer.

And, in spite of depression, the manufacture of luxuries rapidly increases.

No one denies the function of machinery in the production of wealth, and it only remains to establish that the production and accumulation of wealth is not injurious, but, on the whole, beneficent, as by no possibility can its consumption be, in the long run, withheld from the many; and to realise that attacks on the capitalist, in so far as they discourage the amassing of riches, are more likely to lead to the distress than the benefit of the poor, and to the decrease of that purchasing power which is the spring of commerce.

In whatever way we may sum up our estimate of the net effect of labour-saving machinery, there can be no doubt whatever that its use is, in itself, a constant stimulus to invention, and that it will continually increase in efficiency, and in encroachment on the province of manual labour.

Machinery, to use a slang expression, has come to stay, and machine tending is more and more taking the place of skilled handicraft in our staple industries.

The collectivist, as he calls himself, jealous of the success of the successful, advocates, in the interests of the many, the national

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control of all means of production, distribution, and exchange, or the assumption by the State of the duties of the landlord, the factory owner, the railroad and steamship manager, and the banker. The old fashioned virtues of industry, thrift and self-reliance, are to be discarded, but it is not quite clear what is to take their place. The prayer of the collectivist, or socialist—as has been aptly said—contains but two petitions: "Give us our daily bread, and forgive us our debts." I venture to say that the granting of his prayer, and the adoption of his methods, would bring about a depression of trade such as has never been experienced, or even imagined; and it is hard to say in how great a measure the confused mutterings of this sort have been the cause of the diversion of our capital abroad, with the result of inducing a feverish and unhealthy state of trade for a time, a subsequent collapse, and irrecoverable loss.

I deem it rational to hold that the lot of man has been made more tolerable by machinery, his toil lightened, and his opportunities for intellectual and artistic culture increased; but the best of results will not be reaped from its use unless wage-earners of all nationalities will make common cause with capitalists in procuring the withdrawal of all restrictions on the exchange of products and services for money or other considerations, in abolishing tariffs which hinder the production of goods in favourable localities, that they may be fabricated in places which are disadvantageous, and, having repressed their own tendencies to wasteful expenditure, in enforcing a like virtue on their governments, imperial and municipal.

The escape from industrial depression lies in the removal of all obstacles to the steady increase of consuming power, in the setting of rational bounds to militarism, in the mobility of capital and labour—that co-relation between production and consumption may be more readily maintained, and by no means in the return to universal manual labour, or in attempts to realise formless dreams of a government assuming the functions of the universal provider.

It is possible that the benefits, in the form of power to consume, which might reasonably be expected from the use of machinery, and the consequent creation of wealth, have not been so largely or

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so widely realised, or so wisely availed of as a generous sympathy with mankind might desire; but this is not admitting that machinery is injurious, or that destitution is the consequence of opulence, because they exist side by side.

Impatience at the slowness with which the standard of living rises need not amount to denial that it rises at all.

The conditions of labour in the early factories were sufficiently wretched, but they were an improvement on those of the home industries they superseded. Present conditions are immeasurably superior; but it is not generally held that finality in this respect has been reached, neither is it likely that the limit of consumption has been reached, or nearly approached, because, for the time, production appears to have overtaken, and, indeed, to have outstripped it, in the kind of goods hitherto in general demand.

If governments will refrain from what is known by the engaging name of "constructive legislation," and adhere to their primary duty of maintaining security for person and property, private enterprise, on which the State itself depends, may safely be trusted with the work of production and distribution, and the engineer, as heretofore, with the task of devising the means of making the necessaries and comforts of life ever more abundant and more generally accessible.

Mr GEORGE RUSSELL, Vice-President, proposed a hearty vote of thanks to the President for the eloquent and interesting address he had just delivered. He thought it was a very good thing that the President had not taken the advice of the President of Section G of the British Association and dispensed with an introductory address, because this address would be even more interesting to read than to hear. There was matter for thought all through it. There was one point that he had referred to, and that was that no one should be afraid to bring before them a short paper. A great many of the members thought it a very formal thing to write a paper, and that it must be a long paper, and describe something very important. But he was quite certain that a great many of the members could bring forward

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short papers that would raise important discussions, and be more interesting than some long addresses. The Institution of Mechanical Engineers in America adopted a very good idea when they introduced topical discussions. One member might come across a difficulty in his daily work, and, not knowing what to do with it, bring it forward and explain his difficulty, so that every one who had some experience of the matter could take part in the discussion. If they looked at the Proceedings of the American Institution, they would find that these discussions were probably the best of the whole volume. He thought it would be a very great improvement if they could have something like this, which would give an increased interest to the meetings. With these remarks, he had to propose a very hearty vote of thanks to the President for his eloquent address.

The vote of thanks was passed by acclamation.

The PRESIDENT thanked Mr Russell for his kind proposal in regard to his address, and for their response. He would like to emphasise a little what Mr Russell had said about the production of short papers. It was a matter of very frequent experience to find that a paper which occupied a very little time in the reading of it, might give rise to a discussion which would be lengthy and very instructive. He hoped the advice that Mr Russell had given would be laid to heart.

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On "The Construction and Use of Pressure Gauges."

By Mr C. R. L. LEMKES.

(SEE PLATE I.)

Received 17th; Read 23rd October, 1894.

THE following paper is the outcome of a suggestion, which was made in consequence of the interest evinced by members of this Institution in the subject during the discussion on a paper, by Mr Barr, on "Testing Machinery and Electric Water Level Recording Apparatus," which was communicated to this Institution in March, 1893.

The choice of the present time for a review of what has so far been accomplished in the use of pressure gauges is, moreover, a happy one; as this year is the jubilee of the invention of the first pressure gauge. It was in 1844—just fifty years ago—when a Frenchman, Vidi, invented what is to-day known as the Aneroid Barometer, the principle of which has been adhered to in the construction of all metallic pressure gauges down to the present day. Vidi's pressure gauge, or barometer, consisted of a closed vessel with elastic walls, which are pressed in more or less according to the relative pressures inside and out. The tube gauge, or barometer, embodying the principle of the well known Bourdon tube, was first constructed in 1845, by a German, Schinz, and was made for him by a mechanic, Rosekapp, of Coblentz-on-the-Rhine. Five years later, in 1850, M. Bourdon patented this idea, and in 1859 the French courts held that Bourdon's patent had been

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anticipated by Vidi, because Vidi's patent referred to "any form of closed vessel with elastic walls," and the Bourdon tube was held to be included in this. Bourdon was, therefore, ordered to pay an indemnity to Vidi. It may be mentioned that in Germany the Bourdon gauge is to this day known under the name of Schinz. The Schäffer gauge was patented in 1849—one year anterior to Bourdon's patent, and was *the first steam gauge*, as neither Vidi nor Schinz ever contemplated using their instruments for any purpose other than the measurement of barometric pressures.

The simplest form of pressure gauge is the open mercurial column, in which the pressure to be measured is balanced against a column of mercury. This apparatus usually consists of a closed iron reservoir partly filled with mercury, upon the surface of which presses the air or other fluid whose pressure is to be measured. The ascending tube is made of glass, say, in six feet lengths, joined together by means of iron stuffing boxes, and fitted with a boxwood scale; the upper end of the tube being left open to the atmosphere. A column to indicate up to 300 lbs. per square inch requires a vertical height of 51 feet, and in any tall building some wall with a clear flight can usually be found where this can be erected, the column passing through various floors if necessary. The whole length of the column should be fitted with ladders, or other convenient means of access; and a speaking tube, with various flexible tube branches, may be employed for communicating the readings to the observer. The pressure is obtained by means of a hand pump, the medium being preferably air, which is cleaner to work with than water, and precludes the possibility of any error due to a column of water on the mercury. In graduating the mercury column, due allowance must be made for the fall of the level of mercury in the reservoir as the mercury ascends the tube; and to effect this accurately it is advantageous to fit the reservoir with a level indicator, similar to a small iron water gauge. The fall of the mercury in the reservoir depends upon the relative areas of the bore of the glass tube and the horizontal section of the reservoir, and it can be reduced to a minimum by the use of a very shallow

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reservoir of large area, and a glass tube of fine bore. By using a reservoir in the shape of a vertical tube, a large fall in the tube will result when pressure is admitted, and this fact has been utilised for the purpose of constructing a mercury column with a short and convenient scale, the latter being attached direct to the reservoir, which is in the form of a glass tube. In this instrument, as made commercially, the ascending tube, or mercury column proper, is made of wrought-iron, and the scale is graduated by comparison with the open mercurial column. For a pressure of 300 lbs. this gauge has a scale 10 feet long, the ascending tube being, of course, a similar length to the open column—namely, about 51 feet, measured from the top of the scale. Such an instrument has the disadvantage that its accuracy cannot at any time be checked by direct measurement; but if correctly graduated, it will remain permanently accurate, and forms a very satisfactory substitute for the open column where the latter cannot be conveniently fixed. If a mercury column is fixed so as to be subject to material changes of temperature, an allowance must be made for the error due to the expansion of the mercury. On a column 50 feet long, corresponding to a pressure of 295 lbs. per square inch, the variation between the freezing point and 70 degrees F. will amount to 4·32 inches of mercury, which is equivalent to a pressure of 2·10 lbs., and this is a variation which might be experienced even in this temperate climate. The tube of a mercury column, as well as the mercury itself, must be kept scrupulously clean. Unless this is done, the mercury will cling to the sides of the tube, thereby interfering seriously with the reading of the instrument. The glass tubes must, therefore, be cleaned from time to time, and this is best done by drawing a piece of cotton wool through the tube by means of a cord. Metallic wires, especially steel wires, should never be passed through the glass tubes for this purpose, as the slighest pressure against the inner side of the glass will produce a scratch sufficient to shatter the glass with certainty. Before concluding this section of this subject, it might be interesting to enumerate the standards to which the mercury column is graduated for the various measures

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of pressure. At a temperature of 60 degrees F. the height of the mercury column is 2·035 inches for every pound per square inch—which is nearly 17 feet for 100 lbs. per square inch. The English atmosphere is accepted as equivalent to a mercury column of 29·9 inches, and this corresponds to a pressure of 14·7 lbs. per square inch. This standard is in use in Great Britain, United States, Russia, Italy, Belgium, Holland, Sweden, Norway, Spain, Portugal, and Switzerland. On the other hand, in France, Germany, and Austria, pressures are usually expressed in terms of atmospheres, the standard being one atmosphere equals one kilo per square cent., equal to a mercury column 735 m/m, or 28·94 inches of mercury. The French atmosphere accordingly corresponds to a pressure of 14·22 lbs. per square inch, as against 14·7 lbs. per square inch for the English atmosphere, and in making a comparison of pressures upon these standards care must be taken that these values of atmospheres are not confounded.

It should be borne in mind that the pressure indicated by the mercurial column—and the same remark applies to all types of gauges ordinarily used—is simply the amount by which the pressure exceeds that of the atmosphere, and this is evidently a variable quantity for the same absolute pressure, inasmuch as the pressure of the atmosphere varies at different times. Thus, when we speak of 30 lbs. per square inch, we mean the pressure exceeding the pressure of the atmosphere for the time being by 30 lbs., and the absolute amount of this pressure will vary with the pressure of the atmosphere. Under extreme differences of atmospheric pressure the indication of a gauge under precisely the same pressure in a vessel may vary by as much as 1 lb. or 1½ lbs. per square inch. This is an interesting point to bear in mind, although it does not affect the practical value of gauge readings, because at all times the pressure of the atmosphere forms the natural datum line from which the value of all pressures is measured. For practical use, the mercury column has been almost entirely superseded, excepting for very low pressures, by the various forms of metallic spring pressure gauges. Many varieties of these have been invented, but

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the principle underlying them all is that of giving indications depending upon changes of form in a vessel affected by the pressure which is to be measured. The only types of pressure gauges that have permanently held the field are those named after Bourdon and Schäffer; and these are practically the only two types of metallic gauges now generally used. Taking them in the order in which they were patented, I propose first to deal with the Schäffer gauge, which, as already stated, was patented in 1849 by the late Mr B. Schäffer, one of the founders of the firm with which I am connected; and which still stands without a rival in regard to efficiency for certain classes of work. The action of this gauge depends upon a corrugated steel diaphragm, A (see Fig. 1, Plate I.), firmly held between two flanges, B, and to the underside of which the pressure is admitted. The movement of the diaphragm is communicated by means of a rod, C, fitted with a neat little ball joint, D, to a small block, E, held by two small screws, F, in a toothed quadrant, G, gearing with a pinion, H, which carries the pointer indicating on the dial. This mechanism serves to multiply the movement of the diaphragm in such a way that every slight movement is shown on a greatly enlarged scale by the pointer on the dial. A spiral spring of copper, J, is provided on the pinion to take up the slight amount of "play" which is unavoidable between the pinion and quadrant. A very thin protecting plate of silver or silvered copper is placed beneath the steel diaphragm to protect the latter against corrosion. For certain chemical purposes, where acid substances enter the gauge—as, for example, in pulp digestors—the protecting plate is made of platinum. The corrugated diaphragm is stamped out of the sheet, and is, of course, hardened and tempered. These operations require much experience and skill. When completed, each diaphragm is subjected to a series of exhaustive tests under both steam and water, in order to detect any possible defects, and to ensure that it has an ample margin of elasticity under the pressure for which it is intended. In a Schäffer gauge, with 6 inch dial, graduated to 200 lbs., and intended for a working pressure of 100 lbs., the diameter of the free part of the diaphragm, that is, the part

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that moves, is 2½ inches, and the total range of movement of the centre of the diaphragm is ⅛-inch, which movement is multiplied about 80 times on to the dial. The limit of elasticity of such a diaphragm must exceed 300 lbs. per square inch, which is 300 per cent. in excess of the working pressure of the diaphragm. Each individual diaphragm is tested before it is accepted as being fit for use, to ensure that its limit of elasticity lies beyond this point to ensure perfect accuracy of the scale. Each gauge is graduated, point for point, by comparison with two large standard test gauges, which must check one another, and are compared twice weekly throughout their range with the mercury column. The scale being divided, the dial is thereafter written by hand. The Schäffer gauge is manufactured graduated to any pressure up to 400 lbs. per square inch, and may be used for any working pressure up to 300 lbs. At one time my firm made a Schäffer gauge for use at higher pressures by the use of a number of superposed steel diaphragms, and, although this gauge was fairly satisfactory, it has now been superseded by the steel tube gauge, which we shall consider presently.

In the Bourdon gauge (Fig. 2) the essential part consists of a brass or copper tube, K, of elliptical section, bent in the form of a circle, one end of the tube being soldered into a boss, L, by which the steam or other fluid under pressure is admitted, whilst the other end is closed by a cap or plug, M, and is left free to move. When the pressure is admitted to such a tube the elliptical section has a tendency to change to the circular form, and, in consequence, the tube tends to straighten, and the free extremity of the tube moves away from the end fixed to the boss. In the case of gauges with eccentric hand, this movement is communicated direct to a small crank on the spindle of the pointer, and this constitutes at once the simplest and most durable arrangement. But, owing to the shortness of the scale, this type of gauge, though largely used on the Continent, is not favoured in this country. In the ordinary gauge with concentric hand, the movement of the tube is multiplied and communicated to the pointer by a toothed quadrant, N, and pinion,

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O, in a manner closely resembling the arrangement employed in the Schäffer gauge. The works are preferably fitted to the boss carrying the tube, and not to the back of the case, so as to render the works of the gauge quite independent of the case. If the works are fastened to the back of the case, the strain on the gauge case—even such as might be produced by tightening more or less the screws by which the case is attached to the boss—may produce variations in the indication of the gauge. The arrangement of carrying the works on the boss has the further advantage of allowing the use of a loose back, secured by screws, for obtaining ready access to the interior of the gauge; whilst the other alternative of retaining the loose back, and fixing the works behind the dial, is decidedly objectionable. All parts of the mechanism must be fitted up in the nicest possible manner, so as to ensure perfect freedom of movement in the various joints and bearings, without the slightest play in the direction of movement. The Bourdon tubes are frequently made of solid drawn tubes of brass or composition metal. After exhaustive experiments with tubes of every available composition, my firm have come to the conclusion that it is best to make the tubes out of a special brand of rolled sheet metal, which is cut in strips, bent, silver soldered, and drawn in the usual way to the exact shape required; and, although tubes made in this way are far more expensive than the solid drawn tubes, it is found that the extra cost is more than compensated for by their superiority, provided a suitable material is employed. The quadrants in these gauges are made of steel or of a hard brass gearing in steel pinions; and latterly we have introduced pinions of German silver, gearing in quadrants of steel or hard brass. In gauges intended to work under severe vibration—on traction engines, for instance—pinions of steel are employed, working in bearings bushed with nickel; and this is found to work extremely well. The range of pressures within which Bourdon gauges are made is practically the same as for Schäffer gauges.

Referring to the relative merits of the gauges on the Schäffer and Bourdon principles, I think that I can safely assert that as a steam

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gauge—especially for the lower pressures for use on boilers—the Schäffer gauge has never been excelled; and it is an everyday experience to meet with old Schäffer gauges that have been in continuous use for thirty or forty years. There might be many more of the old gauges in use, but for the fact that if some part of a very old gauge is worn out, it is cheapest to replace the gauge by a new one, owing to the difficulty of replacing parts of patterns that have been obsolete for many years. The diaphragm of the Schäffer gauge is far less liable to damage through violent vibration and rough usage than the brass tube in the Bourdon gauge; and the Schäffer gauge is, therefore, unquestionably superior to the Bourdon gauge for outdoor work, and on portable and traction engines, fire engines, etc. For the same reason the Schäffer gauge is at the present day being used in this country almost exclusively on engines for agricultural use; whilst in Germany, and many other parts of the Continent, it is almost universally used for stationary boilers and marine work. The Bourdon gauge, on the other hand, is perhaps neater in appearance than the Schäffer gauge. It is also adapted for fixing conveniently to walls; and, as this gauge, when properly made, is perfectly reliable within certain limits of pressure, when subject to careful usage, it has found great favour both here and in France for locomotive, marine, and all engine work. For high pressure steam, however, the Schäffer steel tube gauge is preferable to the Bourdon gauge with brass tubes; whilst for the pressures with which we are now-a-days accustomed to deal in hydraulic work, the steel tube gauge takes the place entirely of the gauge with brass tube.

The steel tube gauge, Fig. 3, works upon the same principle as the Bourdon gauge, and differs from the latter mainly in having a tube, P, made of steel instead of brass; the other differences being merely points of detail. Some makers employ solid drawn steel tubes, but these are vastly inferior to the tubes turned out of solid steel—provided a suitable material is selected, and the tubes are accurately made and correctly tempered. The tubes in all these gauges manufactured by my firm are bored and turned out of a

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special brand of Sheffield pressed steel, the tubes being made of a large variety of shapes and strengths, according to the pressures for which they are intended. The tubes are bored after the manner of boring the barrel of a gun, and are then turned up on a mandril. They are highly polished both inside and out to remove every trace of tool marks, and afterwards microscopically examined by light reflected from a mirror, any tube showing the slightest flaws or scratches being rejected as being unfit for use. The tubes are then carefully bent and flattened at a moderate heat; and to perform this operation successfully presents considerable difficulty. The tubes are next hardened and tempered, operations which again require much experience and skill. The ends of the tube are screwed into the boss, Q, and cap, R, respectively, and a metallic joint is made at each end by a turned edge, S, bedding into the softer material of the boss, Q, or cap, R. The tubes when completed are subjected to a similar series of tests as those employed for Bourdon and Schäffer gauges, to insure perfect elasticity, and any tube not perfect in its action is rejected. The dial in each gauge is, of course, graduated to its own tube. For hydraulic work, steel tube gauges are made by us daily for pressures up to 10 tons on the square inch, and they have been in some cases constructed with graduations up to 30 tons per square inch. On the other hand, steel tube gauges are also made regularly for ordinary steam pressures; and, by way of experiment, vacuum gauges with steel tubes have even been successfully turned out. The gauges are graduated and tested under pressure of oil, and the oil left behind in the tube, together with the incrustation formed in the operation of tempering, afford protection against internal corrosion of the tube; but, as an additional safeguard, the tubes may be tinned. In gauges for marine use, the tubes are usually tinned both inside and out to protect them against the corrosive action of the sea air. For low pressures, the steel tube gauge has little or no advantage over the Schäffer or Bourdon, and therefore the latter have the preference, being lower in price; but for the high pressures of steam, now so common in land as well as marine practice, the steel tube gauge has

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the decided advantage over the older types as regard accuracy, reliability, and durability, which is greatly due to the more perfect elasticity of steel as against brass. For all working pressures exceeding 100 lbs. we recommend the use of the steel tube gauge; and they are rarely used for working pressures of less than 60 lbs. per square inch.

For standardising hydraulic and other gauges for high pressures, it is necessary to resort to some means other than the mercury column, as it is, generally speaking, impracticable to carry the mercury column beyond about 500 lbs. per square inch, which itself requires a vertical height of 85 feet. For higher pressures, special hydraulic testing machines, in which the pressure is applied by dead-weight, are employed; and much ingenuity is displayed in the arrangement of various devices for reducing to a minimum the errors due to friction and other causes. The readings of these machines can be checked to the greatest nicety by comparison with a mercury column up to, say, 500 lbs. A few years ago, however, a mercurial column of enormous height, and indicating up to 350 atmospheres, or 5145 lbs. per square inch, was fixed to the Eiffel Tower in Paris; and this has afforded the first opportunity of testing practically, and with absolute reliability, to this enormous pressure. A comparison of a standard gauge, graduated from the hydraulic testing machine employed by my firm, revealed an error of $1\frac{1}{2}$ atmospheres, at the maximum pressure of 350 atmospheres; but this small difference was further reduced when corrections were made in the column for certain errors which had at first been overlooked.

When a gauge becomes inaccurate, the only satisfactory way of restoring accuracy consists in redividing the scale; but as this cannot well be done by the user, it becomes convenient to provide means of adjustment in the mechanism of the gauge, whereby any ordinary mechanic can approximately correct any errors. The errors in the indication of a gauge may be two-fold, viz., first, those equivalent to a simple displacement of the pointer. For example when the pointer indicates 2 lbs. too high all round the scale; and,

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second, errors which increase in proportion to the pressure, being, say, 2 lbs. at 20, 4 lbs. at 40, and so on, these being generally a weakening of the tube. The former error can, of course, be corrected, by altering the position of the pointer on the spindle, or, better still, by making the connecting rod, attached to the end of the tube, in two pieces, fastened together by means of screws, in such a manner that the length of the rod can be adjusted. The second class of errors can be corrected by altering the ratio of multiplication of the mechanism, and means for doing this can be provided by making an adjustment where the connecting rod is attached to the quadrant lever.

The pointer is secured by driving same on to the spindle, being usually held by friction, and the spindle is either made square or conical, and slightly tapered. The square spindle has the advantage of greater security for the pointer, but the exact position of the pointer cannot be so readily varied as with a round, conical spindle. The pointer should be perfectly balanced. A stop, or rest pin, is provided behind the pointer, in such a position as to throw the mechanism under a slight strain when the gauge is disconnected. This serves to protect the gauge against damage in cases of slight shocks. The dial of the gauge is preferably made of tin, covered with a thick coat of enamel, which will neither crack, blister, nor discolour under heat.

USE OF GAUGES.

Since the indications of a pressure gauge vary with the temperature of the instrument, it follows that all gauges, when in use, should be kept under the same conditions, as regards temperature, as when they were graduated. When a gauge is fixed on a boiler it is liable to heating in two ways. First, owing to the communication between the steam and the spring of the gauge, and, secondly, owing to the surroundings of the gauge—that is, the heat radiated by the boiler, or otherwise conducted to the gauge. For example, through the fitting which carries the instrument. When steam is admitted to the tube of a Bourdon gauge, the increase of temperature will

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cause the tube to expand, and, as the heating is confined to the tube, an error will result in the indication of the pointer, corresponding to the movement of the end of the tube. Similarly in a Schäffer gauge, the direct admission of steam beneath the diaphragm will affect the indication of the gauge, owing to the difference of expansion of the steel diaphragm and the iron casing. But apart from the errors thus produced, the continuous heating of the tube, or diaphragm, in this way has an effect on the elasticity of the spring, and rapidly deteriorates the accuracy of the gauge. It is, therefore, essential that the pressure of steam should be communicated to the spring through a cool medium, and for this purpose a water syphon is employed.

Regarding the "general heating" of gauges, it may be noted that if the metals employed in the construction of the gauge and mechanism had the same co-efficient of expansion throughout, a uniform increase of temperature of the whole gauge would not produce any differences in the relative position of the tube and the works, and the indication of the pointer would not therefore be affected. In practice, however, it is not possible to make these parts of the same metal, and hence the general heating of a gauge has an actual effect on the indication, the action being similar to that on which the principle of the pyrometer is based. As a rule, it may be taken that serious discrepancies from this cause are avoided if the outside of the gauge when firmly touched by hand feels no more than comfortably warm.

The simplest form of syphon is formed by connecting the gauge with the boiler, by means of an ordinary wrought iron "U" tube. Upon locomotives, a very simple and effective syphon is sometimes formed by the use of a copper tube, which is coiled round the gauge itself. Another very neat, though more costly plan, consists in utilising the tube itself in the Bourdon gauge as part of a syphon. This is done by suspending the tube from the inner boss arranged in the topmost part of the case; the pressure is admitted at the bottom through a separate boss, and the two bosses are connected by a tube passing round the inside of the case. Arranged in this

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way, the water in the gauge tube cannot run out, and the gauge practically forms its own syphon. The modern craze, however, for heavy and showy boiler mountings, has led to the replacement of these simple yet neat and effective arrangements, by the pendant and other heavy brass syphons. These consist essentially of a large pendant tube, T, closed at the bottom, and connected at the top with the boiler. Water collects in this tube, or bag, and another U tube connecting with the gauge dips into this water, the pressure being thus communicated to the gauge through the water in the pendant. This arrangement is satisfactory as a syphon, but compared with the plain wrought-iron tube syphon, it has the disadvantage of forming a splendid conductor of heat from the boiler to the gauge, which, especially at high pressures, tends to produce inaccuracies in the indication of the gauge.

It is customary to fit every pressure gauge with a cock for turning off pressure, to enable the user to disconnect the gauge at any time whilst the boiler is under steam. This practice opens up the danger of damaging gauges by the too sudden admission of pressure. In opening the cocks, if a water pressure, say, of 50 lbs. is admitted suddenly to a gauge graduated to 100 lbs., the pointer will jump far beyond the end of the scale, and the gauge is thrown out of order. Many gauges are ruined daily in this way, owing to the careless operation of gauge cocks, the blame being usually assigned to a defect in the gauge rather than to the ignorance or carelessness of the operator. Wherever sudden changes of pressure are unavoidable, as in many kinds of hydraulic machinery, it is advisable to fit the inlet to the gauge with a pressure check, consisting usually of a small loose valve, V, having a minute passage to serve as a bye-pass. Another form of check valve consists of a small screw let into the connection of a gauge in such a manner that the end of the screw forms a valve against the inlet to the gauge. By adjusting this screw the passage can be reduced to any desired extent, and the whole can be readily removed for cleaning, if the small passage be made up by an obstruction in any way. To effect an adjustment of this screw, the gauge must be removed from

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its work; but this can be avoided by the use of a special screw-down valve with very fine thread, which will work in the same way, but is, of course, much more costly. For use in connection with air, oxygen, or other gas, a very convenient form of check has been patented by Mr W. M. Jackson, of Manchester, consisting of a series of alternate layers of copper gauze and felt inserted in the connection of the gauge, and secured together by means of a screw. In the application of this check to gauges for oxygen bottles—such as are used in connection with the limelight—the primary object of the check is to prevent the sudden admission of pressure, which, in consequence of the compression of the gas in the gauge connection, might set free sufficient heat to produce an explosion, if oil or other combustible matter should be present at the end of the tube. But this check has the incidental advantage of forming a capital protection for the tube and works against damage through the sudden admission or release of pressure.

Defective joints in the connection are also a frequent cause of inaccurate registration of pressure gauges, owing to the connection being partly or wholly made up by the material used for màking the joint. In many cases of this kind the obstruction in the connection acts like a reducing valve, the gauge being thereby caused to indicate in the most erratic manner; and this is particularly misleading, as there is frequently no outward indication of anything being wrong with the gauge. For ordinary steam gauges, the joint is usually made with a lead or leather washer, W; and there is no risk of the connection being made up by this washer if the bottom of the gauge connection is provided with a small projection or pap, X, fitting accurately into a central recess or hole in the union, so as to prevent the washer from gaining access to the passage of the gauge.

In many cases, gauges are also found to be inaccurate, in consequence of the gauge being subject to an initial column of water, as when a gauge is fixed at a lower level than the point where the connecting point enters the boiler, the pipe thus becoming filled with water. The importance of this point will be realised when it

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is borne in mind that, roughly speaking, every 2 feet height of water will make a difference of 1 lb. per square inch in the indication of the pressure gauge.

The accuracy of a pressure gauge, when correctly fixed, depends upon—first, the perfect elasticity of the spring within the pressure limits of working; second, the nicety and accuracy of workmanship of the works; and third, accuracy with which the scale is graduated to the standard; and if these conditions are complied with as nearly as possible, and the gauge is treated with reasonable care, there is no reason why it should not remain perfectly accurate for many years. It has, however, become a matter of frequent remark that few gauges remain accurate after being in use for a considerable time. The chief reason for this is (apart from improper usages already referred to) the springs are so frequently worked beyond their elastic limit, or, to put it another way, the margin of elasticity of the spring of the gauge is not sufficient beyond the pressure at which the spring is ordinarily engaged. The safe limit of working pressure depends upon the material employed for the spring, and also upon the spring being proportioned in the most advantageous manner for the particular pressure, as determined on theoretical grounds by experiment and experience. For a working pressure of, say, 100 lbs., a gauge graduated to 200 lbs. should be employed. A gauge of this kind should safely stand a temporary pressure of 300 lbs. without exceeding the elastic limit—that is, when the pressure is released, the pointer should return exactly to the starting point; but if such a gauge were permanently worked to, say, 180 lbs., it will sooner or later give way—the application for a long time of, say, 180 lbs. having apparently the same effect as the temporary over-pressure to double that pressure in effecting the elasticity of the spring. A gauge of this kind should, however, remain perfectly accurate for many years if it is never engaged above 100 lbs. per square inch. By allowing a still larger margin in the graduation of a gauge, perfect accuracy can be still further ensured, but this is done at the expense of length of the scale.

Test gauges are preferably made in the form of duplex gauges,

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consisting of two complete gauge works fitted in one case, and having two pointers to indicate upon the same dial, each gauge forming a check against the other. The eccentric type of gauge works is the most suitable for test gauges, being simpler and less liable to get out of order than the concentric type.

In Continental countries, users of boilers are compelled by law to fit every boiler with a special flange, or other connection, for the application of an inspector's test gauge, the form of the connection being prescribed by the Government of each country. The gauge cock is usually made three-way, with a lateral branch screwed or made with a flange to receive the control gauge. In Germany, an oval control flange of special dimensions is prescribed; a round flange 30 m/m diameter is used in Belgium; 37 m/m in Bavaria; and a similar flange 40 m/m in diameter for France, Italy, Switzerland, etc. For Austria, the control gauge attachment must be made to receive a test gauge screwed to $\frac{3}{4}$-inch Whitworth.

In this country, comparatively few boilers are provided with any special connection for the application of a test gauge, and the only means of checking the pressure consists in removing the working gauge and applying the test gauge in its place—an arrangement which is altogether unsatisfactory. Many boilers, again, are fitted with connections to receive test gauges, but there is no uniformity in the connections employed; and not only do various insurance companies prescribe different connections, but even in the various branches of H.M. service different standards are in use. I do not propose that we in this country should follow the example of our Continental friends, and compel the use of a particular type of connection on every boiler, nor does the difficulty call for so drastic a measure; but I do think that a great advantage would accrue from the adoption by common consent of a certain form of testing connection. The conversion of existing connections to such standard could be accomplished without difficulty by fitting a suitable intermediate connection.

I have endeavoured in this paper to describe some of the more interesting arrangements adopted in pressure gauges, made by my

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firm, but it should be noted that the modern outcry for cheapness in all things has led to the production of large quantities of gauges in which both workmanship and construction have been entirely sacrificed to cheapness, the outside appearance being the only part in these gauges on which thought and care have been bestowed. This straining for cheapness has been carried so far that the dials of these gauges are printed in one operation without any attempt being made to divide the scale from a standard. An instrument made in this way cannot, of course, be expected even when new to give correct indications. To prevent this paper exceeding suitable limits many special types of pressure gauges have been omitted. There are gauges for rough work—for instance, traction engine gauges, registering gauges, blast gauges, and other low pressure gauges, high pressure gas gauges, alarm gauges, the combined gas regulator and gauge, model boiler guages, and—last, not least—gauges for pneumatic tyres, each of which presents many points of interest to engineers.

The discussion on this paper took place on 20th November, 1894.

Mr R. D. MUNRO, in a written communication, said he had read Mr Lemkes' paper on pressure gauges with great interest, and considered it a valuable contribution to the Transactions. Amongst the many important points so ably dealt with, he felt specially concerned in the reference made to the desirability of having a standard connection for the application of an apparatus for testing steam gauges. In his own practice, he invariably specified such a provision, and he knew this was also done by many others. Each manufacturer of gauges, however, had his own particular method of forming this connection, the result being that an inspector would require to be provided with numerous couplings, and, even then, might fail in getting his testing apparatus applied. The liability of gauges to go out of order was clearly referred to in the paper, and this tendency would probably be more pronounced as the rise in steam pressures became general. The connection might be by means of a flange, as most common in

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Continental practice, but he was of opinion that it would be better to adopt the arrangement used in Austria, where the attachment for the testing apparatus consisted of a socket, screwed to $\frac{3}{4}$-inch Whitworth standard thread. Such a connection would admit of a Richard's indicator being used for testing gauges, a practice somewhat common at present, and would also be more convenient for applying the other forms of test gauges in use in this country. He submitted that it would be advisable for the Institution to take this matter up, and, with the assistance of kindred societies, endeavour to introduce a uniform standard connection for the application of test gauges, as explained in Mr Lemkes' paper.

Mr COPESTAKE said he had seen a great many pressure gauges, but there was one question he would like to ask with regard to the quadrant and pinion, whether there was any wear upon them. There must be excessive motion, and he would like to know whether there had been any destruction in that way? He rather thought that he had heard of failure some years ago, but whether their manufacturer's composition in this instance was strong enough he did not know. It seemed to him that the small pinion had a good deal of work to do.

Mr GEO. C. THOMSON said that he had been troubled a good deal by the want of a connection for attaching the gauges to, when testing boilers, as nearly every boiler tested required a different reducing piece to be made before they could be used. He thought the paper was one of which there was a good deal of need, because the generality of engineers did not trouble themselves very much about the inside of gauges so long as they did their work; it was too much like watchmaker's work. With regard to Mr Copestake's opinion about the pinion, it seemed to him that there was not so much wear on that as there was on the small pinions inside a watch. They all knew that a well-made watch would last a lifetime, and he did not see why this should not be the same in gauges if well made at first.

Mr BURNET agreed with Mr Munro as to the desirability of having a standard connection. He sympathised with Mr Thomson

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in his remarks, but of course there were pinions and pinions. His firm had always found the gauges made by Schäffer & Budenberg so satisfactory that they were never anxious about the wear of the pinion or sector, that was, in their class of work. Last session Mr Sinclair Couper had told the meeting what they had tried in the way of gauge testing, and he thought it might interest some of the members if he showed an apparatus just got from America for testing purposes. It was standing now on the table with a bridle on it. It consisted of a hollow die of hardened steel machined out to a practically true square inch, with a hardened steel cap on top carrying the bridle. If water were pumped into that hollow die, and true weights applied on the bridle corresponding to the increments of pressure shown on gauge dial, one could then, without trouble, test the truth of the gauge reading at any point in the scale. They had found that with a pump acting on the two gauges—one being a standard—the slightest leakage caused unsteadiness and prevented a careful comparative reading being readily taken.

Mr JOHN BARR said he had read this paper with very great interest indeed, and he thought the matter was put very clearly. There was one point, on page 18, where Mr Lemkes stated that "At a temperature of 60 degrees F. the height of the mercurial column is 2·035 inches for every pound per square inch—which is nearly 17 feet for 100 pounds per square inch." He thought it would be interesting to know how Mr Lemkes arrived at that. It might be that that was the standard they worked to, but he could not see how these figures were arrived at. When he worked it out last year, he made it 2·044 inches at 62 F., and on working it out at 60 degrees it came in very nearly the same. It was the same to the third decimal. Although that might seem a small difference (viz., the difference between 2·044 and 2·035), yet, at a pressure of 2000 pounds per square inch, it was 18 pounds per square inch, or nearly 1 per cent. He thought this was a point that should be fully discussed, and it should be something like the electrical and other standards, fixed and established on a satisfactory basis. He happened to pick up a Schäffer and Budenberg gauge the other

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day—he could not tell the age of it—but it gave, as an equivalent for 300 pounds per square inch, 680 feet head of water, which was equal to 2·266 feet head of water for every pound per square inch. He thought the right figure was 2·3, or, more exactly, 2·3121. It was quite possible that gauges now made were graduated more correctly. On page 23 there was something said about the springs getting gradually weaker. That, of course, was quite the case; but he thought that another reason for the steel spring of pressure gauges getting weaker was that by-and-by they corroded. There was something said about tinning the tube to prevent this corrosion. He did not know whether Professor Barff's oxidising process had ever been tried, but he thought it might be worth trying, because it was undoubted that tubes did corrode, and gradually weakened the tube. With regard to the two methods of adjustment, mentioned on page 25, one by shortening the arm, and the other by shortening the leverage (which could be seen in the models), these were very necessary and very handy indeed. He had seen gauges without them. He did not know whether they were now provided for in all gauges, but he had often seen them without these provisions. There was one point about the accuracy of the springs on pressure gauges which had not been noticed there. He was sorry that he had omitted to make the experiment, but he thought, and believed, that there was a certain amount of friction in the spring itself—that was to say, there was a little friction in the movement, leaving out of account altogether the friction of pinion and quadrants, and if they had a spring long enough and big enough to detect accurately the pressures going up and coming back, and to do it gently without any vibration, he was certain it would be found that the spring would not always come back exactly to the mark that it made before. If they put on 100 pounds per square inch, and made a mark, and then went up to 200 pounds, and made another mark, and came back gently, he did not think the spring would be found to come back to the exact mark at 100 pounds as before. He believed there was some friction in the spring itself, altogether independent of that in the gauge movement. It was well worth

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looking into. He quite agreed with what Mr Munro and Mr Burnet said: that it would be a very good thing indeed if there were connections on all steam gauges made to a uniform standard, so that gauges could be tested with a standard gauge at any time, without taking the gauge off.

Mr SINCLAIR COUPER said he would like to support the suggestion of Mr Munro, because there were no other parts of the steam engine that received so little attention as the pressure gauge and the vacuum gauge. We bought them from merchants or from makers, put them on, and accepted them as being correct. They were seldom or never tested after being once set to work. This might appear a small matter, but that was not so, it was really a very important one, and it had been neglected in the past. As his partner, Mr Burnet, had said, they had endeavoured in their business to compare gauges which they sent out, and they found discrepancies, more or less serious, in almost every one of them. They had used the pump shown on the table by Mr Lemkes, and they had since got the small pump from America for testing the test gauge, because it was not everyone who could have a mercurial column. He thought this little instrument was very useful and simple; it was perfectly positive in its action, one pound on the end of the bar was one pound on the square inch, and the action was a constant action. Mr Lemkes, in his paper, described three gauges, the mercurial, the diaphragm or Schäffer, and the Bourdon or tube gauge. The mercurial gauge was inapplicable in most cases, as he pointed out, being too cumbersome for ordinary use. He mentioned, in regard to the Schäffer gauge, that its diaphragm was far less easily deranged than the brass tube of the Bourdon gauge, and although Mr Lemkes did not expressly refer to gauges placed near steam hammers when enumerating the different applications of it, he, the speaker, remembered that in his experience it had been found very useful when placed on boilers in such a situation. The ordinary Bourdon tube steam gauge was very easily deranged, whereas the diaphragm gauge, owing to its construction, gave very little trouble, and was the only type of gauge that could be got to with-

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stand the excessive viabration due to the steam hammers. Another point about all pressure gauges was that they were frequently more or less damaged in the fixing on, when being screwed to their place, and he thought the best attachment was the coupling nut, which was screwed up from the cock on to the nipple of the gauge, but in every case it was possible, no matter what might be the form of attachment, to put on a gauge without seizing it with both hands and wrenching it round. There was another gauge which Mr Lemkes did not mention, or rather another form of the tube gauge. In the ordinary Bourdon gauge the long axis of the flattened tube was at right angles to the plane of the coil, and when the tube was of that construction internal pressure caused it to straighten itself, but he understood it was the case that if the long axis were parallel to the plane of the coil, the coil then tended to close, or the free end tended to come in towards the fixed end. He understood that Professor Thurston had made one on that principle especially for use on locomotives, or where there was much vibration. With regard to the steel tube gauge, he would like to ask Mr Lemkes about the liability to corrosion, and whether simply leaving oil inside the tube prevented this? On page 23 Mr Lemkes said, "The gauges are graduated and tested under pressure of oil, and the oil left behind in the tube, together with the incrustation formed in the operation of tempering, afford protection against internal corrosion of the tube; but as an additional safeguard, the tubes may be tinned." That protection could only be for a very limited time, and he wished to ask Mr Budenberg whether they had found the steel tubes of steam gauges to be affected with corrosion in the form of pitting as they sometimes had in the case of mild steel plates, and also whether tinning was effectual in preventing corrosion?

Professor BARR said, it appeared to him, one of the most interesting parts of the paper was that portion which dealt with regard to the standardising of different gauges. On page 16, Mr Lemkes spoke of the mercurial column, and of the necessity of having a ladder up the whole height of the column. A mercury column had been constructed, he thought, by Mr Casella, of London, having,

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alongside of it, guides, on which a mirror was arranged to travel up and down, and a telescope was arranged at the foot of the column, by means of which the operator was able to see the reading of the gauge for himself, thus avoiding all necessity of having an assistant climbing up and down, and also avoiding the errors which might be introduced by the reading of gauge and the column by different persons. That was a very great improvement upon the ordinary mercurial column. Mr Lemkes referred, on page 24, very briefly to the standardising of hydraulic and other gauges. He would like if Mr Lemkes would give them more information upon the standardising of such gauges, because the greatest difficulties came in when they came to high pressures. There was one method of standardising gauges, above the height that was available with a mercury gauge, to which he might refer. It consisted in applying the pressure that they wished to evaluate to a small ram, attached to which was a larger ram. The larger ram was in communication with the mercury column. The first point was the measurement of the areas of the two rams. That could be done with such accuracy by means of a Whitworth measuring machine, or other micrometer arrangement, that there need be no important error introduced from that cause. The only error that remained, was the very serious one of the friction of these rams, but by causing them constantly to revolve, the friction was entirely got rid of, so far as longitudinal motion was concerned. That apparatus was perfectly satisfactory, he understood, for giving accurate determinations of higher pressures than the mercury column directly represented. He would be very pleased if Mr Lemkes could say whether or not that apparatus was in practical use. He believed that it had proved quite satisfactory when used in laboratories.

Professor JAMIESON was sorry that he had not been present at the reading of the paper, and further, that he had not had an opportunity of studying it at home. There could not be the slightest doubt that Mr Munro's suggestion was well worthy of the attention and support of this Institution. It seemed strange, indeed, that for so many years a separate standard coupling, by

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which to attach pressure gauges to boilers, had been neither universally demanded by insurance companies nor by the Board of Trade. He would like to ask Mr Mollison, or some other gentleman, whether the Government had come to any resolution with regard to testing and certifying standard gauges for steam boilers, in the same way as they had done with regard to electrical supply meters? The Board of Trade had lately started, at great expense, an elaborate standardising electrical laboratory in Whitehall, London. Was there any similar institution in this country under the auspices of the Government, or any authorised society, for standardising steam boiler pressure gauges? If he was not mistaken, this very subject had been discussed at a previous meeting of the Institution, and it was then suggested that for the Glasgow district Lloyd's Proving House should possess a mercurial column (or let them say one or other of the devices mentioned by Professor Barr) so that any person might take their pressure gauges there and have them checked and stamped if correct. Mr Barr mentioned a point which he (Professor Jamieson) thought was wrong. Mr Barr had said that the tube itself had internal friction; if that were so, it would be analogous to what they had in magnetism, namely, hysteroesis, but he did not think the suggested error was due to the tube spring at all. It was, in his opinion, due to the frictional error of the pivots and gearing of the instrument. Did it not seem rather absurd that, at the present day, they should have three or four different ways of registering pressures?

1. Head or pressure of water in feet.
2. Pressure in pounds per square inch (as indicated by steam gauges), starting with the atmospheric pressure as zero.
3. Atmospheric pressures and so called vacuum pressures, as indicated by barometers and gauges in "*inches* of *mercury*," starting with a perfect vacuum as zero.
4. Pressure of a draught of air in inches of water.
5. Absolute pressures in pounds per square inch, as reckoned from 0, or absolute zero of pressure. Example, the back pressure during the exhaust stroke of a steam engine.

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Would it not be far simpler and better in many ways if engineers and others reckoned and measured all pressures from a perfect vacuum as zero? He wished to compliment the author of the paper on the manner in which the subject had been brought before them.

Mr MOLLISON said he did not think he could add much to what he had said in the discussion, the session before last, on Mr Barr's paper on "Testing and Indicating Apparatus." He then referred to the action taken by him to induce the authorities to erect a mercurial column at Lloyd's Proving House, for the purpose of testing gauges up to 360 pounds, the cost of which he had ascertained to be about £30. With regard to Professor Jamieson's question as to the great want of a recognised standard for pressure gauge fittings in this country, he might say that, for marine purposes, this was not so much felt as in the case of fittings for land boilers. The screw and coupling connections, as used by the Board of Trade and Lloyd's Society, were practically uniform, and this, he believed, had led to a uniformity in marine pressure gauge fittings generally. With regard, however, to the fixing of inspectors' test gauges, he was quite at one with some of the speakers as to the difficulties of this, and the amount of time lost in making those connections; and he would like to see introduced into general practice in this country, a flange connection (see Fig. 1) on all gauges, such as they have in Germany, Holland, and other countries, which would enable the surveyor to fix his gauge in a few minutes, besides the results would be more accurate and reliable. For a number of years, Lloyd's surveyors had used a cross conical connection (see Fig. 2, p. 40), which is inserted in the cock of the ship's gauge, after removing the plug, but in many cases these cocks were so light that the cones could not be screwed up sufficiently to make the connection steam and water tight; therefore, the gauges got heated to the boiler temperature, and so became deranged and out of order. They had six or eight duplex gauges in their office for testing purposes, besides a standard one with hydraulic pump, by which means the accuracy of those in use could be tried at any time, and very fre-

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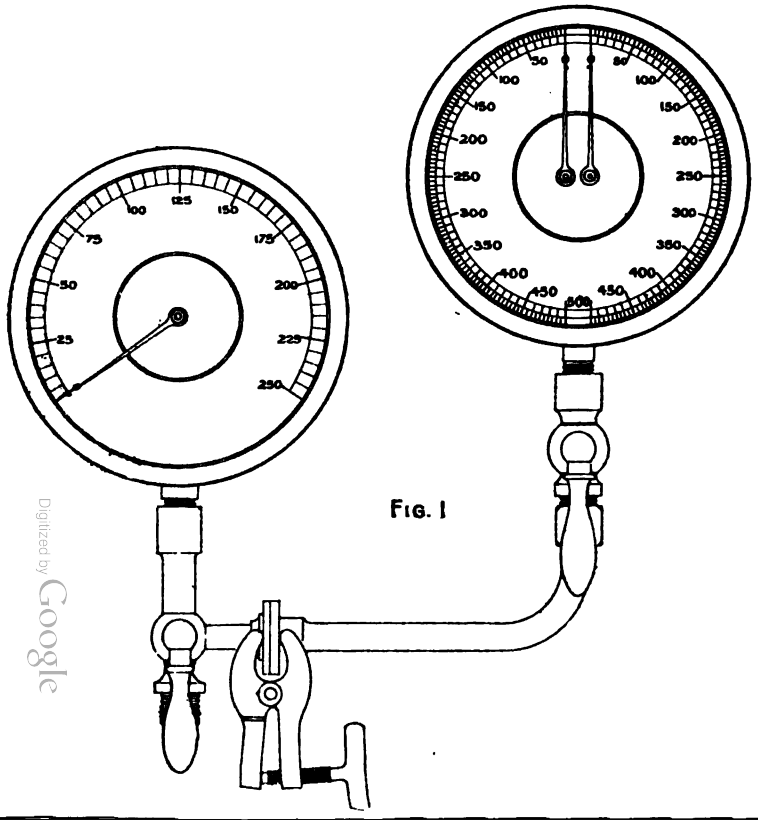

FIG. 1

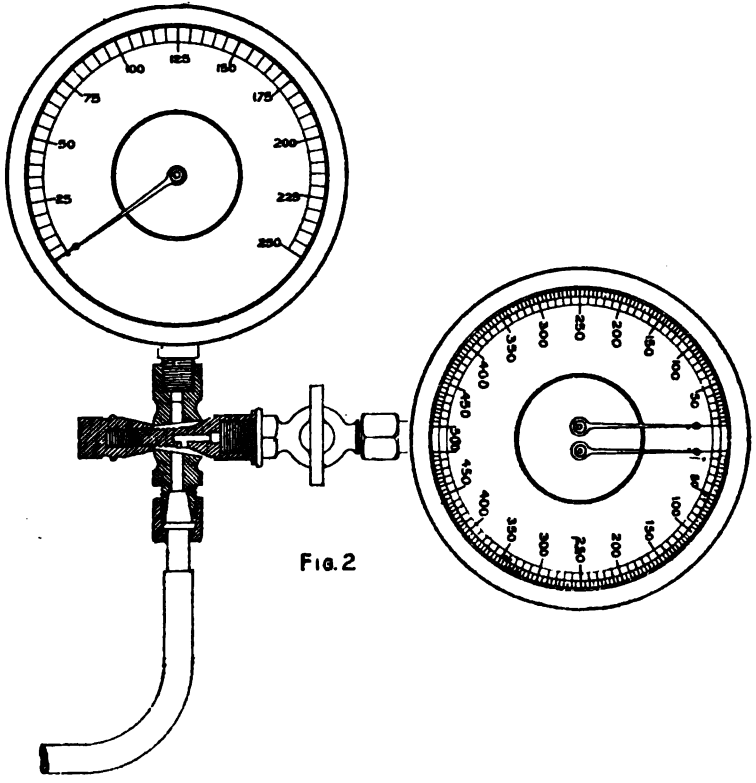

FIG. 2

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quently they had to be taken to the gauge makers and adjusted by such means as they had, either by dead-weight load or hydraulics, which, of course, was not so satisfactory as would be the case if tested and adjusted by such a mercurial column as described so fully in Mr Lemkes' paper; and he thought some one might be philanthropic enough to erect one, for the public benefit, in this city.

Mr BIGGART said they would observe from the remarks that had fallen from Mr Mollison that experts even were not all of one opinion as to the proposed standard connection that should be put on boilers. Mr Barr had referred to friction in the gauges, and was of opinion that some of the springs had a certain amount of friction within the material of which these were composed, but he (Mr Biggart) did not think that that was the case. If they took a spring, or any form of bar, and stretched it within its elastic limit, then he thought there was no doubt but that it would come back to exactly the same position when the stress was removed, and that without any outside assistance. Otherwise perfect elasticity within the limits of such was a myth. He remembered himself carrying out some rather delicate experiments with regard to wires, varying in length from 100 inches to 100 feet, and out of a great number of experiments they tested these to stresses varying from 5 tons per square inch up to and beyond the elastic limit. So long as they were within the elastic limit every length came back to exactly the same position at which they started, but whenever the elastic limit was passed a portion of the stretch remained permanent. He believed the same laws applied to springs or any other form of steel or iron whatever.

Mr SINCLAIR COUPER had no hesitation in saying that it was the Government that was behind the day, because every Government that had paid attention to these matters had got such provisions. It was very likely that within the next few years we would have an Act of Parliament regulating the construction and the use of steam boilers generally. He saw the name of Johannesburg on the map hung up for Mr Moore's paper that night, and that reminded him that they would not think that a Boer Government would know

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very much about these things, but it had laws affecting steam boilers, with provisions regarding that very point.

Mr BUDENBERG explained that Mr Lemkes had asked him to reply to the technical questions that had been asked. He had read the paper through carefully, and he substantially agreed with everything that Mr Lemkes had said. There were one or two matters that were not quite correctly expressed. As an example of what he meant, it was stated that the present year "is the jubilee of the invention of the first pressure gauge." It should read, "of the first *metallic* pressure gauge," as gauges, in the shape of mercurial column gauges, had been in use long before. Mr Copestake had asked a question with regard to the wear on the pinion and quadrant of pressure gauges. If the metal used in the pinion or quadrant, or in both, were too soft, then they were liable to wear in cases where the pointers were subject to much vibration, and many cases of this kind had come under the speaker's notice. There was, however, practically very little chance of wear if the quadrant were made of a hard brass composition, gearing in pinions of steel. They had recently introduced pinions of German silver gearing with quadrants of hard brass or steel, which worked very satisfactorily, and were practically proof against wear. The German silver was very awkward to work, but the difficulties were in a fair way of being overcome, and ere long they would fit all gauges with German silver pinions. Mr Barr had said that the standard of graduation named in the paper, and in use at their works, was not correct. In reply, he would like to point out that their standard was the one that was generally recognised and endorsed by the leading authorities in this country and abroad, and was based upon the atmosphere of 29·9 inches being taken as equivalent to 14·7 pounds per square inch, making the pounds per square inch equal to 2·035 inches of mercury. Mr Barr had taken it upon himself to say that this was wrong, and he had put together a collection of various values, assigned by different authorities, for the specific gravity of mercury. The values he gave differed widely, and he appeared to have struck a kind of average, and said that that must

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be the basis of the correct graduation. He arrived at the conclusion that the pounds per square inch must be taken as 2·044 inches of mercury. The difference between the two standards was $\frac{9}{20}$ per cent., and not 1 per cent., as stated by Mr Barr; and, moreover, the value for the specific gravity of mercury, corresponding to the recognised standard of pressure, was well within some of the figures that Mr Barr named in his paper. Referring to the question of spring friction, the speaker thought there was probably something corresponding to friction in every spring, but the amount of this in pressure gauge springs was certainly so slight as to be practically imperceptible on the dial of the gauge. It was the *friction* in the *mechanism*, referred to by Professor Jamieson, that was so detrimental to accuracy of indication in many gauges, but the back lash of the gauge pointer could be practically entirely overcome if the mechanism were made as free as possible. Reference had been made by several speakers to the question of corrosion in the steel tubes. There was, of course, no doubt that the steel tubes in gauges were liable to corrosion, and for this reason they would not recommend the use of steel tube gauges for low pressures where a brass tube gauge answered every requirement, but before they got to a very high pressure they arrived at a point when the brass tube could not stand, and they were bound to use steel for the tube if they wished to have a reliable gauge. But if some amount of corrosion was perhaps inevitable, yet it might be kept within harmless limits, if suitable precautions were observed. The corrosion was really caused by the presence of carbonic acid or other acids present in the air, or water that came into contact with the tube. If a gauge is attached to a boiler, the slight amount of acid present in the water, contained in the tube and syphon, might produce some slight corrosion, but there it would end, as the acid would soon be neutralised, and no further action would occur so long as the gauge was left in place. Thus a gauge might be in use for many years without practically any corrosion taking place. Moreover, a considerable amount of corrosion would have to occur before the indication of the gauge could be materially affected.

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It was, however, quite a different thing if a gauge was used at intervals, the water in the tube being replaced each time the gauge was used and the air gaining access meanwhile. If necessary, the whole difficulty could be overcome by completely filling the gauge tube and syphon with oil or glycerine, and providing only a small opening for communicating the pressure from the boiler to the syphon. Corrosion could thus be entirely obviated in steel tube steam gauges, and the question merely resolved itself into one of going to the expense and trouble in making this provision. A question was asked as to whether all gauges were now provided with the means of adjustment referred to in Mr Lemkes' paper. As a matter of fact, opinions varied considerably among engineers as to the desirability of providing these adjustments. On the one hand it was agreed that these adjustments were a great convenience in enabling any mechanic to roughly adjust a gauge, whilst others thought that they simply constituted a temptation to tamper with the gauges on the part of men who could not be expected to be acquainted with these details. They were prepared to meet both views, and, according to requirement, supplied gauges with or without the adjustments as the case might be. Personally, the speaker held that it was desirable to fit the second adjustment referred to at the top of page 25; the other adjustment was not so important, because they could always make that correction by removing the pointer and driving it on in another position. He had no experience of the Thurston gauge referred to by one speaker. As to the standardising of high pressure gauges, he regretted he must ask to be excused from giving details of the machines that they employed. He would, however, go so far as to say that they used a *piston* testing machine, which was rendered frictionless by the peculiar arrangement of a diaphragm to make the piston tight. They used a piston two inches in diameter, and did not think satisfactory accuracy could be obtained with a piston only half an inch in diameter, as employed by Mr Barr. He could not agree with the statement made by Professor Jamieson that all gauges should be graduated from absolute zero. That was all very well in

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theory, but was scarcely of advantage in practice. Take the case of a boiler. The shell was under a stress which was the difference between the internal pressure and the outside atmospheric pressure, and it was this difference which was indicated by the gauge. If the boiler gauge indicated absolute pressure, the pressure of the atmosphere would have to be deducted from the indicated pressure to arrive at the pressure that determined the stress on the shell. And so on throughout our practice, the pressure of the atmosphere formed the natural normal from which all effective pressure must be measured. Moreover, a difficulty would arise in making a gauge to indicate true absolute pressure, as means would have to be provided in the gauge to compensate for the variations of atmospheric pressure. A pressure of say 20 pounds above the atmosphere might require to be indicated as 35 pounds absolute pressure to-day and as 34 pounds absolute to-morrow, according to the variation of atmospheric pressure. The adoption in this country of a uniform connection for the application of test gauges, would certainly constitute a great boon to engineers and, if there was any chance of success, it was a matter worth fighting for. But he thought there would be great difficulty in finding the connection that would suit everyone, and it would not be easy to enforce the use of a particular type of connection. The 1½-inch diameter control flange, which was, he believed, used by the Admiralty, and also formed the standard connection in France, would be found to be the most serviceable; but, on the other hand, it would be difficult to find a stationary boiler in the whole length of the land that was at present fitted with this flange, whereas there were many boilers fitted with a connection for ¾-inch Whitworth thread, and as regarded land boilers at anyrate, this connection would be the type most generally acceptable. He thanked the Institution for the attention they had paid to his remarks, and it was a great pleasure to him to give them what little he could of his experience.

Mr JOHN BARR asked leave to make a remark with reference to what Mr Budenberg had said. Mr Budenberg had said that he, Mr Barr, had taken several specific gravities of mercury, added them

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together, and taken the average; but he did not do that. He took the specific gravity fixed by the British Association Electric Standards Committee as being correct. His reason for drawing attention to the standard used by Mr Lemkes' firm was that the figures he gave did not agree with the standard specific gravity of mercury. At present it seemed "we do not know where we are." If Mr Lemkes' paper did nothing else, it had been serviceable in showing that it was absolutely necessary that the standard equivalent of mercury to the pound per square inch should be fixed, and not subject to variations either one way or another; also in showing the necessity of having a uniform practice with regard to the connection of test gauges to pressure gauge connections on boilers.

Mr BUDENBERG agreed with the remarks made by Mr Barr, and on the point of facts he readily gave way to what Mr Barr had said, but as regarded the standard of pressure he thought the stand they took was the only one open to them. A committee of the British Association might arrive at a new value for the specific gravity of mercury, but that was no reason why they should jump at it and make that the basis of a new standard. The new value might be nearer the truth, or it might not, and to-morrow another authority might publish another figure, said to supersede that determined by the British Association. They worked to the standard which was so far recognised and endorsed by all engineering authorities, and they would adhere to this until some other standard had in some authoritative way been given to, and sanctioned by, the engineering world. With very few exceptions every one seemed to be satisfied with the standard to which they were now working.

The CHAIRMAN, in moving a vote of thanks to Mr Lemkes for his paper, said that the paper must have cost Mr Lemkes (who was the representative of a very eminent firm of pressure gauge manufacturers) a great deal of thought and trouble, and it contained a great deal of information. It was a paper that they would be glad to have in their proceedings, and he proposed a hearty vote of thanks to Mr Lemkes for giving it.

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The vote of thanks was heartily accorded.

Mr LEMKES said he was very much obliged to the meeting for the attention given to his paper, and he begged to thank the members for the vote of thanks.

Note received from Mr John Barr, 3rd December, 1894.

Referring to discussion on Mr Lemkes' paper on pressure gauges, I, to-day, made an experiment with a large gauge tube of thin section, with a view of ascertaining whether there is any friction in the spring itself.

The tube formed a circle 17½ inches diameter (less 7 inches of its circumference). With a pressure of 25 pounds per square inch, measured very accurately by a small mercurial column, the movement at end of tube was 2¼ inches. The result was that the rising and falling pressures were exactly alike—that is to say, the position of spring was exactly the same when pressure was put on or let off—and not the slightest friction was discernible. So that, if the pointer does not stand at the same point with rising or falling pressures in a gauge, the cause must be friction of the gearing and movements.

I thought it right to communicate this, as it was a common belief, which I shared, that there was friction in the spring itself, causing it to give varying indications when pressure was rising or falling.

The tube experimented with was of brass, 1 inch wide, of the section used for vacuum gauges, and was exceedingly delicate, answering to the least variation of pressure. J.B.

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On "The Witwatersrand Gold Field."

By Mr Robert Thomas Moore, B.Sc., C.E.

(SEE PLATES II., III., AND IV.)

Received and Read 20th November, 1894.

There is no surer way of attracting people to a new country than the discovery of gold in it. This has been proved several times in comparatively recent history. It was the "gold rush" in 1849 which peopled California; the gold discoveries in Australia which brought people out to that country; and it has been the gold fields which have opened up the Transvaal.

Certainly the Boers occupied the country for many years before the gold mines were started, but the Boers were hunters and farmers, each family holding a farm of from 6,000 to 10,000 acres, cultivating about 20 acres of it, but doing nothing to develope the mineral resources of the country. They were not miners, those sturdy Boers. Many of them think even yet that the gold is the ruin of the country, stocking it with those sinful "Uitlanders," who make railways and so spoil the transport riding, run their batteries on Sundays, and so provoke the Divine wrath that the locusts have been sent to devour the country as a punishment for their sins. That the miners are the cause of the locusts there can be no reasonable doubt, for they were never seen in the country before the mines were opened up. And so they are selling their farms and "trekking" north to countries where they can hunt the "wilder beeste," and be no longer troubled with the "verdomte rooinek," as they somewhat contemptuously designate an Englishman.

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Several gold fields have been opened up in the Transvaal. The Lydenburg gold field, with its alluvial diggings, was working in 1872; the De Kaap gold field, with its famous Sheba mine, which was opened up in 1885, was working in 1873; but it was not till 1884 that the Witwatersrand, or, as it is shortly called, the Rand gold field, was discovered. The Rand gold field is by far the most important in the Transvaal. This will at once be seen when it is stated that out of a total output in 1893 of 1,610,335 oz., 1,478,477 oz. came from it.

I shall confine my remarks to this Rand gold field.

Although much has been written on the Rand gold field, I do not think its magnitude, and the enormous quantity of gold which will be raised from it, are as fully recognised in this country as they ought to be. I visited this field in February last, and was much struck by its importance, and I venture to submit the following remarks to the Institution on this wonderful deposit.

The present workings, enormous though they be, are merely in their infancy, and much work will be done in the near future in largely increasing the quantity of gold coming from it. Most of the machinery required will come from this country, and for many years it will be an important market for British machinery and productions.

The Rand gold field lies on a level plateau from 5000 to 6000 feet above the level of the sea. Johannesburg, the chief town in it, is 1000 miles to the north-east of Cape Town, 440 miles north-west of Durban, and 400 miles west of Delagoa Bay. (See Plate II., Fig. 1.)

The country is a flat, rolling prairie, with no trees. In the summer, which is the wet season, it is covered with grass. In the winter, when there is no rain for several months, this gets burned up, and the whole country looks barren. The heat is great during the day, but it is always cool at nights, and the climate is very suitable for Europeans.

Although the gold was discovered in 1884, it was not till 1887 that any quantity was worked. In that year 23,128 ounces were raised, and the output has been increasing by "leaps and bounds,"

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and from 1887 to the end of 1893 4,556,235 ounces had been raised.

In 1886 Johannesburg was a camp with a few tents. It is now a town of 40,000 inhabitants, with a main street two miles long, with two storey and three storey brick buildings on each side, with tramways, and lighted both by gas and electricity. Until 1892 everything had to be conveyed in bullock waggons from Kimberley or from Natal, but in that year it was connected with Cape Town by rail, and now the express train, which has dining and sleeping cars, travels the thousand miles in forty-eight hours.

OWNERSHIP OF THE GOLD.

All the gold belongs to the Government, who proclaim any property as a gold field whenever they are satisfied that it contains gold in payable quantities. A certain area of the estate, called a "Mijnpacht," is reserved to the proprietor, who has also other rights, but whenever a public gold field is proclaimed, any white man who has paid his personal taxes can peg out a claim on about four-fifths of it.

The extent of a claim is 150 Cape feet* along the line of outcrop and 400 feet to the dip, or about 1½ acres.

For this he pays a tax of £1 a month, and one-half of this goes to the proprietor of the proclaimed farm and the other half to the Government.

It is evident that one claim is not sufficient to establish a mine upon, and a good deal of manœuvring is done by moneyed men in getting parties to peg out claims for them. Most of the claims on the proclaimed farms which are supposed to be workable are now taken up. Many of them are held by people who have no intention of working them themselves, but pay licences in the hope of selling them to somebody who wishes to start a mine. And pretty large prices they ask too—invariably asking a considerable proportion of it in cash.

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* 30 Cape feet are equal to 31 English feet

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Almost everybody in Johannesburg holds, or says he holds, a claim somewhere.

Before a company establishes a mine, a number of claims are purchased, frequently from several holders. In some of the mines the area held is as much as 200 claims, or nearly 300 acres. The licence duties on this holding would amount to £2400 a year.

A public gold field will only be proclaimed after it has been proved to the satisfaction of the Government that gold has been found on it in payable quantities.

The Government take considerable pains to ascertain this. In a recent case where considerable stir was made over a new gold field, and several syndicates had been started in this country to form companies to develope it, the Government sent down their engineer, who reported that the ore did not contain gold in payable quantities, and refused to proclaim it.

GOLD-BEARING BEDS.

The Rand gold field differs from almost every other, inasmuch as the gold-bearing material, instead of being found in veins or lodes, as is usually the case, lies in stratified beds like the seams of coal or ironstone in our ordinary coal fields, and is worked in the same way as we work coal or ironstone. Those gold-bearing seams are conglomerates of quartz pebbles, bound together with silica and iron. They are locally known as "banket" reefs, "banket" being the Boer word for the sweetmeat almond cake, the pebbles in the banket looking like the almonds in the cake. The gold is found in the matrix surrounding the pebbles, and there is little or no gold in the pebbles themselves. There are several seams of banket, varying in thickness from 6 inches to 40 feet, and carrying on an average from a trace of gold to 2 ounces per ton, though sometimes patches are found carrying up to 40 ounces. The average yield of all the mines in 1893 was 13$\frac{1}{3}$ dwts., or £2 6s 9d per ton of 2000 lbs.

The intervening strata are mostly hard sandstones, or quartzites.

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The seams of banket are divided into six different series in the same way as we speak of the upper and lower coal measures.

These are, beginning with the highest—

1—The Black reef series.
2—The Elsburg reef series.
3—The Kimberley reef series.
4—The Bird reef series.
5—The Main reef series.
6—The Duprees or Rietfontein series.

It is possible, and indeed likely, that many other beds, or "reefs," as they are locally called, may be found. The vertical distances between the series have not been accurately ascertained. The deepest bore-hole yet put down strikes the Main reef series at a depth of nearly 400 fathoms, and it is supposed to pass through the Bird reef series—which is at that point barren—at a depth of 60 fathoms. A journal of this bore is given in the appendix.

The Main reef series is the most important, and the mines, with only one or two exceptions, are situated on it.

It has been traced along its northern outcrop for a distance of 45 miles, dipping to the south at inclinations varying from 80 to 15 degrees, and all along this distance mines have been established.

A railway, belonging to the Netherlands Railway Company, who have the sole right of making railways in the Transvaal, runs nearly along the line of these mines from Krugersdorp, past Johannesburg and Boksburg to Springs. From Boksburg to Springs, and connected with the railway, are large collieries, which supply fuel to the various mines.

A fair idea of the extent of the operations may be had if we assume the North British Railway from Edinburgh to Glasgow to be the outcrop of the Main reef series, and Falkirk to be Johannesburg. There are mines dipping to the south, marching with one another, and fitted up with machinery, all along this distance, and almost all of them are in operation.

The Main reef series consists of five reefs—

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The South reef.
The Middle reef.
The Main reef leader
The Main reef.
The North reef.

They are all comprised in a distance of 150 feet. The thickness of the seams and the distance between them varies, the most persistent being the Main reef, which is a large reef, as thick as 20 feet, and seldom less than 5 feet. It contains generally from 4 to 5 dwts. of gold per ton. In one or two places, however, it is richer, and is now being worked. Almost all the mines have been started, and are working on one or other of the thinner reefs, only one or two of which are found in workable condition at any one mine. Fig. 2, Plate II., shows the outcrop of the Main reef series, with the position of some of the more important mines. The dip of the seams is given at various points, and figures are marked showing the number of pennyweights of gold got per ton of ore from the mines at the points indicated. These figures are taken from the Chamber of Mines' report for 1893. Fig. 3, Plate III., is a plan and elevation of the workings of the City and Suburban Co. in one of the reefs. It shows the regularity of the seams.

MINES.

The mode of opening up the mines has been by sinking shafts or by driving dip inclines from the surface in the seam, breaking levels from each side and forming pillars, which are afterwards worked away as in a longwall coal working. Winding engines are placed on the surface, and the banket is drawn up the incline in skips or carriages, which run on rails. It is drawn from the faces in tubs, and these are emptied into hoppers at each level.

There is little water in the mines, and it is raised by steam pumps, electric pumps, or the ordinary rod pumps. Each mine is fitted with arrangements for crushing and milling the quartz, all of which are worked by steam power. The boilers are usually tubular, and are worked at 100 lbs. pressure.

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The water needed for the mills is collected in reservoirs.

Considering the short time which has elapsed since this field was opened up, it is surprising to see how well the mines have been laid out. This is due to their being mainly in the hands of large companies, who have employed skilled English and American engineers to lay out the mines and the machinery.

The companies have also established a Chamber of Mines, which gives, monthly, copious and accurate reports of the ore raised, the quantity of gold yielded, and many other interesting and useful statistics.

The labour is entirely done by Kaffirs, superintended by white men. The Kaffirs who work in the mines come from long distances —some of them from over the Zambesi—and none of them are permanent residents. They, almost all of them, go home after working six months, but often return after they have been away some time. They are paid so much a month, and are supplied with food, which consists of mealie, or maize meal, which they make into a kind of porridge. The average wage on the Rand is 58s 10½d per month, or, including food, about 3s a day. They live in compounds at each mine. These are simply galvanised iron sheds, and the men lie on the ground. Each man provides his own bedding, which consists of a blanket and a wooden pillow.

There are several tribes working in each mine, and each tribe keeps to its own compartment.

They are steady labourers, but require to be told exactly what they are to do.

There is difficulty experienced in getting sufficient Kaffir labour at present, and this will probably be one of the chief difficulties of increasing the output.

White men are paid from £4 10s to £6 per week.

DESCRIPTION OF MINE.

I give a description of a mine on the Main reef series, which I descended, showing the mode of working the ore and getting the gold from it.

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This mine has a holding of about 50 acres, and it is calculated that it will last twenty years at the present output of 150 tons a day. The following is a section of the seams of banket which it contains (see Fig. 4, Plate IV.):

	Thickness.	
Quartzite,	-	
Thin reefs (poor).		
Quartzite,	- 18 to 20 ft.	
No. 2 South reef,	2 to 16 ins.	Carrying 3 and sometimes as much as 30 oz. of gold per ton of ore.
Quartzite,	- 6 ft.	
No. 1 South reef,	6 to 18 ins.	Carrying 1 to 3 oz. of gold per ton of ore.
Quartzite,	- 6 to 12 ft.	
Main reef,	- 4 to 5 ft.	Carrying 18 dwts. of gold per ton of ore.
Quartzite,	- 12 inches.	
North reef,	- 6 to 8 ft.	Comparatively poor, carrying 5 to 7 dwts. of gold per ton of ore.

The seams worked are the Main reef and the Nos. 1. and 2 South reefs.

The incline, which is driven from the surface following the inclination of the seam, is at present 400 feet down. It is 15 feet wide and 6 feet high, with two lines of rails in the middle, a stairway for the men going down and up, and a space for pumps on the side. The water is light. There are two electric pumps capable of discharging 4000 gallons an hour, but only one is kept working, and that not constantly. The dip is 60 degrees, getting slightly flatter at the bottom. Two skips travel in the incline for drawing the ore out of it. These are worked by steam engines placed on the surface, and are independent of each other. Levels are broken from the incline. The first pair of levels is at a distance of 150 feet from the surface; the second at 300, and the third at 400. One

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skip takes the ore from the first two levels, and the other from the third level and from the face of the incline.

At each landing a cross-cut is driven to the other reefs, and they are all worked in the same way.

The levels are driven 7 feet square whatever be the thickness of the seam.

At every 130 feet, places 7 feet square are driven connecting the two levels, thus forming pillars 123 feet long and about 120 feet wide, which are afterwards worked out. These "throughers" are driven half-way up hill and half-way down, meeting at the centre. Rails are laid in the levels, and the ore is drawn out in iron side tipping tubs, holding about 15 cwts. each. They are emptied into a hopper on the side of the incline, and the skips are filled from these hoppers. Every effort is made to push on these levels so as to open up fresh ground, and they are driven at the rate of 60 feet a fortnight. There is no pick work, everything being done by blasting with dynamite, as many as 13 holes being blasted in the face of the level. These holes are bored with rock drills worked by compressed air. Each machine is in charge of a white man, with two, and sometimes three, Kaffirs, the white man charging and firing the shots. The cost of driving the levels with machines is more per foot than by hand labour, but the speed of driving is greater, and this is of more importance than the extra cost.

The pillars were being taken out in the first and second levels. They are worked out by a kind of longwall working. Operations are commenced at a througher, and the working is broken away to both sides. (Fig. 5, Plate IV.)

The banket is worked in strips, 6 feet long, each strip following the other, and a Kaffir working in each strip. There is no pick-work; all the ore is broken down by blasting. Each Kaffir bores two to four holes by hand, and at the end of the shift, a white man, who is in charge of every twenty Kaffirs, charges the holes and fires them. The Kaffirs then come in and clean up the ore which has been broken down. Only the banket is worked, but when this is under 2 feet in thickness, some of the sandstone is worked along

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with it, so as to make the working 2 feet wide. In such a case, the ore and sandstone are filled together and sent to the surface, where the sandstone is picked out.

Small pillars of ore, 7 feet square and 30 feet apart, are left along the top side of the levels, and a solid rib, 10 feet wide, is left on the low side of the levels. Pillars of the same size are left every 30 feet, or so, in the waste, and chocks of wood, about 7 feet square, are put in where required, but, beyond these, there is nothing left to support the roof, which is very good. So far as I saw there was no subsidence, as in a longwall working, but this will have to be provided for, as the seam flattens, and greater depths are reached. Rows of wooden props, 5 feet apart, with boards on them, are put in every 30 feet, and ore is allowed to lie on them to give standing to the men. The ore worked is run down "spouts" to the level, and at the foot of each spout there is a wooden box with a door, which is opened to fill the ore into the tubs. When a new row of props is put up, the ore lying on the one below it is kept as a store, and when it is required, the props on which it is resting are taken out, and it is run into the tubs.

The mine works two shifts—from 6-30 a.m. to 5-30 p.m., and from 7 p.m. to 5-30 a.m., and 300 Kaffirs are employed.

Careful plans are kept of the workings.

Great care is taken to ascertain the richness of the ore as the work proceeds, and for this purpose a sample is taken in each level every six feet and assayed, and the yield of gold and the thickness of the seam are registered and marked on the plan. By this means an accurate estimate of the quantity of ore "in sight" can be made. The following are the thicknesses of the lodes and the assay values for distances of 100 feet on each of the three seams worked:—

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No. 1 South Reef. Thickness. Inches.	Yield p. ton. Dwts.	No. 2 South Reef. Thickness. Inches.	Yield p. ton. Dwts.	Main Reef. Thickness. Inches.	Yield p. ton. Dwts.
18	15·47	3 + 36	93 + 181	48	27·75
18	12·6	4 + 20	76·7 + 78	48	25
9	91·2	20	37·8	48	27·25
6	19·14	39	88	44	38
6	59·4	36	52·9	43	14
6	20·3	30	164	42	17
10	43·1	30	99	36	29·5
15	10·8	27	60	36	21·7
30	11·8	21	56·5	39	26
24	17·1	30	65	36	24
36	2·34	24	599	36	32
6	34·7	22	88·2	32	32
9	31·4	52	49·1	32	32
22	11·3	40	7·9	36	32
		24	97·3	48	28·3
		43	119	42	24·3
		32	221	48	23·7
				60	18·3

When I visited the mine the quantity of ore in sight was :—

	Tons.		
Main reef, above 1st level,	17,040	valued at 16½	dwts. p. ton.
Do. between 1st and 2nd levels,	16,500	„ 10	„
South reef, No. 1, above 1st level,	13,250	„ 18	„
Do. between 1st and 2nd levels,	5,800	„ 35	„
South reef, No. 2, above 1st level,	8,870	„ 24	„
Total, -	61,460		

Average value, 18 dwts. per ton.

TREATMENT OF ORE.

The ore, after being brought to the surface, is treated as follows :—

The skip carrying the ore to the surface empties it over a "grizzly," or screen, with 2 inch spaces between the bars. The ore which passes through the screen goes into a hopper. What passes over it is put into two Blake crushers, and, after being broken, passes also into the hopper. Iron tubs are filled from this, and

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drawn along a line of tram rails for about 50 yards to a cage, which raises them to a hopper behind a battery of 40 stamps.

STAMPS.

It is fed from this by an automatic feeding arrangement to the stamps, and water is run in at the same time. Each stamp weighs 950 lbs., and crushes 3¾ tons of ore per day to such a fineness that it will pass through a wire gauze with 900 meshes to the sq. inch. There is mercury in the mortar box, and this catches the larger proportion of the gold. The crushed ore, after being flushed through the wire gauze, passes over copper plates in front of the stamps.

The stamps are run 24 hours a day, and 7 days a week. They are stopped for a day at the end of each month for a complete clean up, when the plates are changed, but the amalgam is scraped from the plates with indiarubber scrapers every four or five days.

The amalgam got from the plates is roasted, the mercury is distilled and condensed, and the gold is left. This is fused, run into moulds, and made into golden "pigs." These are worth £3 10s per ounce.

CYANIDE WORKS.

There are no concentrators, but the crushed ore runs direct from the plates to the cyanide works. These are at a higher level, and the water and crushed ore or tailings are raised by a 30 feet lifting wheel with buckets. The tailings contain a large proportion of slimes, which are fine mud, and it is found impossible to treat them in the cyanide works unless the slimes are taken out, as they pack among the sand and prevent the cyanide solution from percolating through it. In this mill, which is one of the most recent, considerable pains are taken to get rid of them. The tailings are passed through a spitzlutte, where an upward flow of water carries off the slimes, which are lighter than the rough tailings, and thus about 40 per cent. of the tailings, containing from 3 to 4 dwts. of gold per ton, are taken out—the gold in them is lost.

The rough tailings run in a launder from the spitzlutte to large wooden vats, 24½ feet in diameter and 5 feet deep. They are run

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into them through an indiarubber hose, which is kept moving all over the vat, so as to spread them uniformly, and prevent any packing which may keep the cyanide from getting at any portion of them. There are three drains along the side of each vat for the water to run out of, and slabs of wood are put in as the level of the tailings rises in the vat, to cause the water to drain off at the top.

There are six vats for holding the tailings, and four for holding the cyanide solutions. The cyanide vats contain solutions of different strength. Two of them contain a solution of ·32 per cent. of cyanide of potassium; one of them of ·28 per cent., and the other of a little less than ·28 per cent. When the vat is filled with tailings, the weakest solution of cyanide is run through it. Then the two strong solutions and the ·28 per cent. solution are each allowed to stand with the tailings for 12 hours, and after that the tailings are washed with pure water.

The cyanide solution runs from the vat through a pipe into a tank below. A pump lifts it from this to the zinc boxes, and by putting a suction on the tank, assists in drawing the solution through the tailings. The zinc boxes contain fine zinc shavings, and the cyanide, containing gold in solution, is caused to flow through them in an upward direction, and the gold is precipitated. There are four lines of boxes, and each is kept for one strength of solution.

The whole process occupies three days.

The cyanide solution, after passing through the zinc boxes, is made up to its proper strength, and is used over again.

The zinc is changed about twice a month. It is taken up and shaken, and then riddled through a very fine riddle, and the fine stuff, which contains the gold, is taken out of the bottom of the boxes as a fine slime. The shavings which remain are put back into the boxes, and a fresh quantity is put in to make up for that which has been dissolved.

The reduction is made by the slimes being roasted, so as to volatilise the zinc. They are then fused with borax in a plumbago crucible, and the gold is got as a button in the bottom.

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The gold got from the cyanide works is from 600 to 800 fineness, and is worth about £3 an ounce.

The assay value of the ore was 18·2 dwts. per ton of 2000 lbs., and of this there were extracted :—

In the mill, - - -	11·2	dwts. or	61·5	per cent.
„ cyanide works, -	4·3	„ „	23·7	„
Making a total extraction of	15·5	„ „	85·2	„

The tailings from the mill contained 7 dwts., so that the proportion recovered by the cyanide process was about 60 per cent. The proportion of gold recovered by the cyanide process, from the actual tailings treated, appears to be about 74 per cent.

The value of gold got from each ton of ore treated was £2 12s 1½d.

The costs of getting this were :—

			s.	d.
Mining, - - - - -			15	3·2
Milling, - - - - -			3	4·5
Transport, - - - - -				4·7
Maintenance, - - - -			2	2·0
Charges, - - - - -			2	4·2
Mine development redemption, -			5	0·0
Tailings—Cost,	s. 4	d. 7·4		
Royalty,	1	5·9		
	6	1·3		
Cost per ton of ore milled,			4	1·0
In all, - - -			£1 12	7·6

Leaving a profit of 19s 6d per ton of ore.

The amount of money expended on the mine has been :—

Mine development, -	£28,840
Permanent works, -	8,402
Buildings, - - -	11,196
Waterworks and dam,	4,850
Plant and machinery,	58,647
	£111,935

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The nominal capital is £85,000. They are paying a dividend at the rate of 80 per cent. per annum. I see the £1 shares are selling at £7¾, so that the market value of the mine is £658,750, and the rate of dividend at the market price is about 10 per cent. This, however, is a very good mine.

In 1893, there were 74 companies mentioned in the list of the Chamber of Mines. Of these, 24 paid dividends, amounting, in all, to £1,065,203. Twenty-six companies, on the best part of the Rand, crushed 1,411,000 tons of ore, yielding 922,047 ounces of gold, worth £3,227,000. The average cost was 33s 6d per ton of ore; the average price realised was 45s 6d, showing a profit of 12s a ton.

Out of these 26 companies 16 paid dividends.

EXTENT OF THE GOLD FIELD.

I shall now try to give an idea of the extent of this wonderful deposit.

The area which contains it has not been thoroughly proved, and probably some time will elapse before this is done.

The main reef out-crop has been opened up from Krugersdorp, 24 miles west of Johannesburg, for a distance of 45 miles eastwards to Boksburg. (See Plan, Plate II.) There are faults, as in a coal field, which throw the out-crop north and south, but it practically stretches in a continuous east and west line for this distance of 45 miles, dipping to the south at inclinations varying from 80 to 15 degrees.

At the eastern end the beds are overlaid by coal measures, but 20 miles to the south-east of Boksburg they re-appear at the Nigel mine dipping to the north-west, and 5 miles west of Heidelberg they are again seen dipping to the north. West of this they are again masked by the coal measures and other rocks, and no out-crops are seen until a few miles south of Krugersdorp, where the dip is to the east.

The field thus appears to be a large basin.

A bore put down on the Simmer & Jack Co.'s property, at a

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distance of 4000 feet from the out-crop of the main reef, struck that seam at a depth of 2400 feet, which is a workable depth.

The deepest workings on the main reef are not more than 700 feet vertically from the surface.

The inclination in the workings, which is steep at the surface, flattens in depth, and this deep bore shows that at that depth it is getting still flatter, and it is more than likely that at greater depths it will continue to flatten until it is quite flat. This flattening in depth is usually found in coal fields. In the Edinburgh coal field, for instance, which this Rand basin very much resembles—at Dalkeith, the coal seams, which near the surface are dipping at from 1 in 1½ to 1 in 2; at 400 yards back are at a depth of 150 fathoms and dipping at 1 in 3; at 400 yards farther are 250 fathoms deep and are dipping at 1 in 5, and in a short distance farther are perfectly flat. If the same flattening takes place on the Rand, and it seems highly probable that it will, shafts sunk to the dip of the deep bore will not be nearly so deep as has been anticipated. This can only be proved by further deep bores, and it is very desirable that these should be put down, for if it is proved that pits can be sunk to the seams at workable depth, there is no end to the quantity of gold which may be produced yearly.

Very few people consider the enormous quantity of gold which this field may contain.

Assuming the field to be a basin, and that the dotted line on the plan is the southern out-crop of the main reef series, it embraces an area of more than 1500 square miles. The dotted line is a mere guess, and may not be at all accurate. As already explained, the southern out-crops are covered with other rocks, and it will require much investigation before they can be laid down with any degree of certainty. It is hardly to be expected that the whole area would contain workable gold; but when it is remembered that a square mile, only 3 feet thick, contains 6½ million tons, which at 13 dwts. represents 4,225,000 ounces of gold, this area would contain an inexhaustible supply at the present output, even from the main reef

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series alone, without taking into account any of the other reefs, and perhaps all at workable depths.

Taking, however, the distance between the out-crop and the deep bore, there may be a belt 1300 yards wide, which may be said to exist along the whole length of 45 miles. Assuming a workable thickness of all the reefs in the main reef series of 5½ feet, this would give 400 million tons still to work, or 130 years' work at the present rate of output.

Although, however, the out-crop has been opened up for this distance, the richest and most regular portion of the reef, and that on which the most profitable mines are situated, is the 12 miles near Johannesburg.

Assuming that the belt is only worked in this area, it will yield 100,000,000 tons, or 33 years' output. There are, however, shafts in Belgium working coal at a depth of 600 fathoms, and there is no doubt pits will be sunk to much greater depths than the deep bore, and in that case a much greater quantity of reef can be got.

In any event, there seems to be no reason to doubt that for 50 years the present output, or a very much larger one, may be got. The probability is that this is a very low estimate indeed, and that the field is practically inexhaustible.

There would be no difficulty in sinking shafts of 600 fathoms deep. A shaft of this depth, completely fitted with machinery capable of raising 1000 tons a day (and this is a larger quantity than is treated by any company on the Rand), would not cost more than £150,000.

This would be the only additional cost over the fitting up of an outcrop property, as the cost of milling and all other plant would be the same. The cost of working the ore at this depth would probably not be more than at the outcrop, as the reef would probably be flatter and more cheaply worked.

If, say, 350 acres of claims at this depth were got at a reasonable price—as could readily be done—a fitting on it would be a much

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better speculation than buying shares in the existing mines at the present market prices, which are in some cases 16 times their original value.

Comparing it with the Langlaagte Estate and Gold Mining Company, which has the largest output on the Rand. This mine has 160 stamps, and in 1893 it milled 222,273 tons, at a profit of £140,100. It has an original capital of £470,000, and the present market value of this is £1,997,500.

Taking the cost of sinking a 600 fathoms shaft and fitting it with machinery as £150,000, the cost of milling and all other machinery and plant as £200,000, and the cost of claims as £200,000, a mine of the same dividend earning capacity as the Langlaagte Estate could be started for £550,000, or for £1,447,000 less than the present market value of Langlaagte shares. The 350 acres would last 30 years, and if 20 years life were considered sufficient, larger dividends could be earned by a comparatively small additional outlay on milling machinery.

The banket is a low grade ore, and consequently it is only by the expenditure of large sums of money on extensive machinery that a mine can be made to pay. It would be safe to say that there is no good attempting to start a mine even on the outcrop without being prepared to spend £30,000 on it.

There are no rich places where a digger can start and make a fortune by finding some rich nuggets, as in Australia, and really there is very little chance for the old time prospector who carries his implements on his back.

It is essentially a capitalists' field. There is less risk in a gold mine on the Rand than in a colliery in Scotland, for the mining risk is no greater, and there is no risk of low prices for the gold as there is for coal, and with proper precautions in securing a field, and skilful management, there is every prospect of getting a large and steady return for money invested in it.

I have not touched upon the coalfields in the neighbourhood of these mines. They are practically inexhaustible. The present

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output is about 500,000 tons a year. One colliery which I visited was raising 266,000 tons a year from a shaft 17 fathoms deep, and the thickness of the seam was 20 feet.

Appendix I.

Journal of the Rand Victoria Deep Bore.

	Depth in feet.
Surface soil and sandy blue clay	10
Small boulders in same	18
Friable shale changing to yellow clay, which hardened to rock at	98
A gradually hardening shale, blue in colour, and with undecided stratification	126
A three-inch quartz seam	138
Flagstone (?) of a greenish blue colour, with a little lime	150
Blue shale, laminated with occasional layers of metamorphosed sandstone; dip of strata here 60 degrees	167
A stratum of quartzite, one foot wide	193
Blue slate with quartz pebbles	197
Three-inch layer quartz	220
Quartzite with few small pebbles, intermixed with sandstone layers	252
Sandstone layers	288
Sandstone with some pyrites and hydromicaceous seams	296
Pebble seam, three inches, in a series of vitreous sandstones and grits, all much metamorphosed	303
Beds of banket matter (?) probably coarse grits	333
Vitreous sandstones and quartzites, and commencement of Bird Reef series	337
The Bird Reef series of banket beds, consisting of alternating strata of barren banket and sandstone, dip here 50 degrees to	366
Sandstones	367
Pyritic Banket Reef	368

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	Depth in feet.
Average dip of footwall here 50 degrees. A further series of sandstones, grits, and seams of bankets with hydromicaceous partings, until two reefs, each 6 inches thick, are encountered at 384 and - - - -	385
Four-foot banket bed - - - - -	389
An eighteen-inch banket bed - - - -	391
A three-foot banket bed - - - - -	405
A series of quartzites with some grits, terminating in a pyritic quartzite with some stray pebbles, the average dip of the strata being 50 degrees at - - -	426
Highly vitrefied sandstones, and quartzites - - -	427
A series of hard blue quartzite, having an average dip of 47 degrees - - - - - -	440
Reef matter, giving blank pannings - - -	479
Fine grained sandstones, with few small pebbles, some small grit seams, and having a dip varying between 30 and 40 degrees - - - - - -	508
A fairly well defined reef, but barren - -	548, 7 in.
An immense series of hard blue quartzites, with some sandstones, frequent seams of grit or reef matter, a few layers of white quartz and occasional stray pebbles, terminating in a 21-inch barren reef at -	915
Another large series, of a similar nature to the last, but with a dip increasing up to 45 degrees again, and terminating in a reef, barren, but one foot wide, at - - -	1127
A similar reef at - - - - - -	1152
Another similar series of quartzites, vitreous sandstones, and grits - - - - - -	1153
Intensely hard grey shale, with a somewhat conchoidal fracture, dipping at angle of about 45 degrees - -	1529
Medium dark grey quartzite - - - -	1580
Very pebbly strata - - - - - -	1582
Green pyritic shale, in seams of a pebbly quartzite - -	1590
A few inches of barren banket in a coarsely pebbled quartzite	1594

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	Depth in feet.
Coarse quartzite, with very few parting seams	1598
A one-inch seam of solid pyrites in quartzite, the dip being 44 degrees	1605
A one-and-a-half inch of a dark micaceous shale	1607
A series of curiously varying quartzites, some coarse and gritty, some schistose	1614
A pyritic banket bed	1635
One foot of banket, which contains gold, and is said to belong to the Livingstone series	1637
Dip 27 degrees at	1638
A series of 6 banket seams, nearly all blank, and where gold is found in but minute traces, commencing at	1642
And terminating in a quartzite at	1667
Coarse and fine quartzites, with pale coloured bands, dipping on an average 23 degrees	1668
Another large series of quartzites, of all degrees of fineness, from almost perfect homogenity to a coarse grit, sometimes hydromicaceous, sometimes schistose, and occasionally almost transparent; average dip about 22 degrees, terminating at	1860
Three feet of an undefined rock, which crumbled away, the core being thus lost, probably a hydromicaceous schist	1860
A series of fine schists, with some small seams of very small pebbles	1878
A continued series of the same, with more frequent thin bands of conglomerate, the dip of the strata being as low as 13 degrees	1913
Distinct bands of pyrites and pyritic partings	1973
Pyritic partings, with curiously deceptive grains resembling gold, having the lustre of tin chloride, and really formed by hydrated ferric-oxide	1977
A further series of schists and quartzites, with some white quartz veins, and frequent stringers of conglomerate, the pebbles being from an eighth to a quarter inch diameter	1978

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	Depth in feet.
Dark grey shale, with white quartz and pyrites streaks	2027
Quartzites, and more frequent thin seams of conglomerate (banket)	2028
Scattered pebbles	2040
Five-inch white quartz vein	2047
A further series of quartzites, less schistose, but containing frequent beds of conglomerate	2048
Mottled quartzites	2092
Distinct pyrites bands	2095
A series of pyritous conglomerate seams, with frequent seams of pyrites, and very pebbly strata throughout	2096
Joints of pyrites	2163
White quartz 4 inches	2167
One inch of solid pyrites	2173
Pyrite crystals scattered throughout the strata	2204
Dip of strata average 15 degrees	2205
A series of very pebbly strata of quartzites	2206
Eight inches of banket with ¼-inch pebbles, the outside fringe of the Main Reef series	2277
The South Reef	2343
The Main Reef	2397

In this bore the Main Reef Leader is supposed to have been got 18 inches thick at 2391 feet, and assayed in some samples as high as 10 ounces per ton, showing visible gold. The Main Reef gave an average assay, through a thickness of 4 feet, of 1 oz. 15 dwts.

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Proposed Change on Bye-Laws.

At the General Meeting on 18th December, 1894,

Professor BARR moved that No. 10 of the Library Bye-Laws be altered to read "Books shall not be lent to any person except members, associates, or graduates of the Institution, or members of kindred Institutions to whom the Council may grant the privilege, upon such terms as the Council may from time to time determine;" instead of as at present, "Books shall not be lent to any persons except members, associates, or graduates of the Institution." The immediate occasion for this proposal was that they had received an application from the Glasgow Association of Students of the Institution of Civil Engineers for library privileges. This matter had been under consideration for a considerable length of time. It was discussed by the Library Committee at the end of last session, and was brought up before the Council at a recent meeting, with the result that it was down on the billet for the consideration of the Institution this evening. The question had a two-fold aspect: on the one hand the proposed alteration, if given effect to, would benefit the Society by increasing the funds at their disposal for the provision of books for the library; and, on the other hand, it would benefit those young engineers in Glasgow who were so anxious to get library privileges here, as the library of their own Institution was inaccessible. He hoped that the meeting would approve of the change of bye-law. It would be noticed, from the terms of the motion, that the proposed arrangement was one which could be terminated by the Council at any time, because it reserved to the Council the right to make such arrangements from time to time as they thought advisable. Should they agree to the motion he believed the Council of the Institution of Civil Engineers would be willing to enter into an agreement with the Council of this Institu-

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tion for the carrying on of the arrangement, so long as the Council of this Institution saw it to be to the advantage of the Institution, and to the benefit of the Students' Association.

Mr MOLLISON seconded the motion, and said it must give them great satisfaction to think the Library was likely to be taken advantage of in this way. For a good many years the number of members and graduates visiting the Library was only six or seven per day; now, he understood, the number of visits had gone up to over one hundred, showing the growing desire amongst the young engineers of this city to avail themselves of such a Library.

The PRESIDENT said that this motion was recommended by Professor Barr, honorary librarian, and Mr Mollison, a former member of the Library Committee, and well acquainted with the use to which the Library was being put. The alteration had been unanimously approved of by the Council, but it was open to any member to object to it if he saw good reason.

On being put to the meeting, the motion was unanimously agreed to.

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On "A New Mining Motor."

Use of Electricity for Power Transmission in Mines.

By Mr HENRY A. MAVOR, Vice-President.

(SEE PLATE V.)

Received and Read 18th December, 1894.

THE ever increasing size and depth of mines, as minerals are worked out of the more easily accessible fields, call for the application of power at ever increasing distances from the points where power can be conveniently generated. The use of mechanical power for the operations of ventilation, hauling, pumping, and coal cutting is gradually increasing, while the conditions of work in the mines are becoming such as to render the use of the older methods of power transmission increasingly difficult. Transmissions of power by steam, air, water, or ropes, all present increasing difficulty as the distances are increased, so that the attention of mining engineers is now strongly directed towards the possibilities of power transmission by electricity.

The wise conservatism which prefers to proceed upon the lines of the old and painfully acquired experience is from time to time broadening its base and including in its grasp another weapon with which to grapple with new or increased difficulty.

The beautiful simplicity of electrical apparatus goes far to compensate for the disadvantages introduced by the application to the mine of another style of plant to which the miners have to become

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accustomed, and the great efficiency under suitable circumstances of electric plant more than compensates for the losses incidental to the transformation of energy from one form to another. It is not to be supposed, however, that the electrical engineer pleads for his methods of power transmission a universal advantage over all the established methods. In most cases it will be found that for simple transmission, up to about half a mile from the source of power, the older methods will be less costly, and as efficient for moderate powers. The losses due to transformation of mechanical to electrical energy, and the retransformation to mechanical energy, bear too large a proportion in such cases to the loss in transmission to admit of a favourable comparison with any method where the energy is directly transmitted without transformation. For longer distances electricity shows a rapidly increasing advantage in first cost and in efficiency, and also in the important element of convenience. Electric cables and electric motors are the most compact and portable means for conveying and using power underground, and in such operations as coal cutting and dook pumping, the ease with which the power may be made to follow the work is of enormous advantage.

These general questions have, however, been pretty fully gone into in Mr Scott's paper, read before the Institution in 1891, and in the discussion on that paper, and need not more be enlarged upon.

The conditions of coal mining specially require that any machinery used in the mine must conform to certain conditions, all of which may be met by an electric motor constructed specially for mining purposes. The first essential is certainty of working. The motor must not break down; it must be light and easily handled; it or its parts must be of such a size that they can be conveniently passed down the shaft and along the roads; it must be efficient; and lastly, it must be as cheap as possible, consistently with these other requirements. Power plant underground is usually vitally connected with the working of the mine. If the pump, fan, or hauling rope stops, the least possible result is serious and prolonged

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inconvenience. Now the state of matters in a coal mine is not such as is most conducive to the welfare of electrical apparatus. The temperature is high; dust and damp are in the air; and the engineers are accustomed with ponderous slow running plant requiring little attention. The motor must therefore not only be well constructed mechanically and electrically, but it must be suited for working under conditions to which in ordinary circumstances electric plant is not subjected.

Considerations of economy and efficiency tend to the use of as high an electric pressure as possible, but for the generality of coal mining work in this district, an E.M.F. of 500 volts is found to be sufficiently high. The insulation of armatures for this pressure is comparatively simple, but great care has to be taken in all dynamo machines that they are of sound mechanical structure. This presents some considerable difficulty, because the electrical and magnetic requirements are not on the whole consistent with the mechanical conditions.

As is well known to most hearers of this paper, the action of the electrical motor depends on the force exerted between what is called a magnetic field and conductors carrying an electrical current. To attempt to explain this action to engineers who have not given any study to the question generally leads to failure and mutual recrimination. Undeterred by the experience of others, I make another attempt in the hope that it may be possible to convey some idea of the mode of action as it presents itself to the mind of the electrical engineer.

Although it has to be admitted that the whole matter is still in the region of speculation and hypothesis, it must also be borne in mind that many of the operations in nature are involved in much deeper mystery. The bases of the phenomena of life are hidden in still impenetrable obscurity, and the cause of such a familiar phenomenon as that of gravitation is so far from being understood that Lord Kelvin wrote of it only last year:—"Absolutely nothing has been done either by experiment or observation towards deciding between Newton and Bernouilli as to the question of its propagation through

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a medium, and up to the present time we have no light even so much as to point a way for investigation in that direction."

Strangely enough the much more recently obscured phenomena of electro-magnetism have led to the development of theories which have all the appearance of consistency with the observed phenomena. Without entering into any elaborated quotation of authorities, I will give you what appears to be the most approved way of looking at the phenomena with which we are concerned in studying electric motors. For our present purpose we need concern ourselves only with such electric currents and such magnetism as we have to do with in continuous current motors—that is to say, motors driven by current of approximately steady flow in one direction. As current and magnetism are but two aspects of the same phenomenon, it matters little from which end we attempt to unravel their connection. Beginning then with the electric current, we must picture to ourselves that wherever an electric current is started in a conductor there is set up all round it in the medium—which has been postulated for the convenience of natural philosophers, and which they call the ether—a whirling disturbance. This disturbance is at right angles to the direction of the current, and seems to answer to the description of a vortex ring. The ring rotates with the current as its axis. It is supposed that this ring is made up of whirling electricity, so that it has, like the more visible and familiar vortex rings of smoke, two motions without change of position. The motion round the axis of the rings produces the phenomena of magnetism. We may then represent a section of our electric circuit as being surrounded by a whirl in a definite direction. It so happens that the direction of this whirl, in relation to the direction of the current, is represented in driving a right-handed screw home.

Thus a current into the plane of the paper would have a whirl as shown by the arrow. Now place alongside of it another conductor

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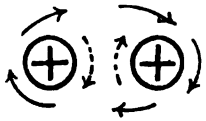
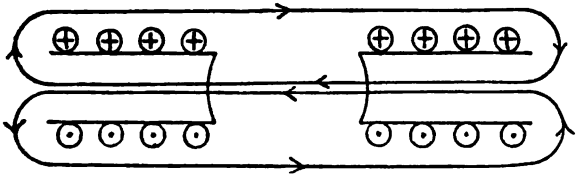
similarly carrying current, and we have a whirl enclosing the two conductors, the stream of lines continuing in the direction of least resistance.

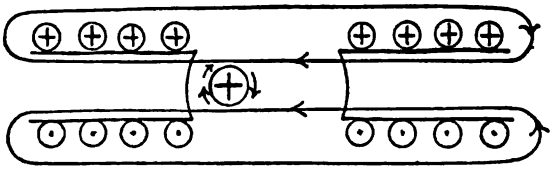


The strength of this whirl or whirls, which is what is called the magnetic field of the current, depends on the nature of the substance or substances through which it passes. In a path consisting entirely of air, its strength is very small. In a path consisting of iron or steel, its strength or intensity is very much greater.

A group of such whirls might be represented thus—



If, now, a conductor with whirls of its own be introduced into this group of whirls, or magnetic field, we are in a position to guess how it will behave—



It will be seen that the whirl in the intruding conductor opposes the stream of lines on one side and adds to them on the other; the tendency therefore will be to move towards the direction in which

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it is pushed by the most lines. That is upwards in the case shown in the sketch. This is, in fact, the action of the electric motor. Electric currents are sent in from an outside source and made to flow in the directions indicated, and the result is motion in the direction shown. The aim then in designing an electric motor is to provide as nearly as possible a continuous iron path for the magnetic whirls set up by the exciting current, and so arrange the conductors carrying the currents to be moved across the magnetic field at right angles, that they shall interrupt this iron path as little as possible, and that they shall transmit the driving force to a point where it can be applied to do work. This is now practically accomplished almost universally by essentially similar methods. A portion of the iron path is mounted on an axis, and is free to revolve. On this portion are mounted the driving conductors, which transmit to the axis the force exerted by the interacting currents and magnetic field by exerting a turning force at the periphery.

To get this force applied as it is wanted, it is necessary to confine the electric current to the copper conductors, and to so mount those conductors on the core that they will transmit the forces to the shaft.

Now, unfortunately, the substances which are suitable for insulating or confining the current to the conductors are none of them metals, and are not suitable for transmitting mechanical strain. It is for this reason that so much difficulty has been found in making motor armatures thoroughly sound in mechanical construction.

There is no doubt that experience has shown that the most satisfactory method of mounting the conductors is to place them in channels in the iron core as shown in the diagram. (See Plate V.) The common method of simply binding them to the smooth surface of the core has often led to trouble from the shifting of the conductors on the surface. That method would never have been adopted but for other difficulties, again electro-magnetic as distinguished from mechanical, but which are fortunately rather a matter of ancient history than of practical present day importance.

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There are other mechanical details applied to the construction of the motor which is more specially under our notice to-night, which have done much to make the armature more satisfactory. Chief among these is the method of putting on the wire.

The usual method of winding such armatures is to start with a single conductor, and wind it by hand on the core from end to end. This is a most laborious process, which has the further disadvantages that the first turn of wire is covered up by all the succeeding turns, that the first turn to go on to the shortest, and the last the longest, no two turns being exactly the same length, while in the ends of the armature the wires are heaped up in a most unmechanical fashion. (The Gramme, or ring winding, is free from some of these defects, but has to be carried out entirely by hand.)

The method adopted in the machine under consideration is to wind in a separate former, a coil for each slit in the core. These formers are wound in the lathe, and are all precisely similar in every respect. These separate coils are then set round the core, one in each slot, and are driven down to the bottom of the slot, one side of the coil half filling the slot, and the other side standing up above the periphery of the core. The projecting sides of the coils are then grasped simultaneously by a suitable tool, which keeps them in a fixed position, and the core is turned round through a half circle. The coils are thus twisted round, so that the projecting half comes to be diametrically opposite the half which has been imbedded in the slot. The tool is then removed, and the projecting wires are slipped into the slots lying beneath them, and the main winding of the armature is complete, making a perfectly mechanical and symmetrical job, easily accessible for repair, and readily open to inspection. Two difficulties are thus overcome. A perfect positive mechanical drive is obtained for the conductors, and the mechanical difficulty of insulation is much reduced, because, instead of an indefinite number of possible points of contact between wire and wire, and between wire and core, we have a fixed number of places requiring protection, and these places are all in similar positions, so that the omission of the necessary protection can be determined by

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inspection. One of the chief difficulties to be overcome in all continuous current electric motors is the tendency to spark at the brushes which transmit the current, by the commutator, to the moving conductors of the armature. Even in well designed motors sparking is liable to occur with changes of load. This can be got rid of to a large extent by changing the position of the brushes with change of load, but it is not always convenient to do this, especially in motors used for intermittent work, such as hauling or coal cutting. A device invented by Mr W. B. Sayers, and well known to electrical engineers, has to a large extent got over this difficulty, and experience in its use will probably enable motor builders to design and construct motors of any size, which will run sparklessly at any load without any necessity for changing the position of the brushes. The explanation of the action of this device is too complicated and technical for others than specialists in this work, and it will be sufficient to say that it has been successfully applied to machines up to the size of machine shown in the diagram, with perfectly satisfactory results as regards sparking, the brushes remaining fixed for all loads. Formerly, considerations in connection with sparking fixed a limit to the air space or gap between the magnets and armature, so that this could not be reduced to the dimension otherwise desirable. The use of this device has enabled us to reduce the air space to the very small dimension shown in the diagram. The effect of this shortening of the air space will be at once evident from what has been said about the magnetic field—the intensity of the magnetic field, or group of magnetic whirls, set up by the conductors wound on the field magnets, depending on the nature of the substances which form its path. Iron increases this intensity, while air does not; therefore, the less air there is in the path, the less magnetising force will be required. This means that less current need be sent round the magnets, and, therefore, that less space is required for wire. It is this primarily which has enabled us to make a practical motor entirely enclosed in metal, and yet which is not excessively heavy or unwieldy. This has been made still more attainable by the advent of what is practically a new material. In

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the old days, cast-iron was the material principally used for field magnets. The researches of Dr Hopkinson and Mr Gisbut Kapp demonstrated, without doubt, that dynamos ought not to be made of cast-iron, and wrought-iron for many succeeding years held the field. This is now destined to give way before steel, so called, which is really chemically pure iron, obtained by the process used for making steel. To enable me to illustrate the advantage of using this material, I will endeavour to give you a slight outline of the nature of the differences of these substances in the property of intensifying magnetic whirls, or stream lines, which as we have seen is an essential and vital element in the construction of dynamo electric machinery. The diagrams which have been placed in your hands are intended to illustrate this property in different materials. (See Figs. 3 and 4.)

The two smaller curves (Fig. 3) are taken from those published by Messrs Krupp. They are tests of grey cast-iron and of wrought-iron, which seem to have as good magnetic properties as any which have come under my notice. The largest curve (Fig. 4) is taken from those published by Messrs Allen, of Sheffield, and is the result of independent experiments by Professor Jamieson and Professor J. A. Ewing, which are so nearly in agreement that the curves given by those two distinguished experimenters are practically identical.

The abscissæ, H, in this curve represent the magnetising forces produced by electric currents made to circulate in a conductor wound round the iron; the ordinates, B, represent the resulting magnetic induction. It will be seen that the curves are double, enclosing in each case an area.

The curve in each case represents a complete cycle of magnetisation starting from, and returning to the middle horizontal line—that is to say, the experiment starts by sending a feeble, steady, continuous current round the iron; the resulting induction is measured, the current is increased step by step, measurements of the induction being made at each step, until it is found that increasing the current does not appreciably increase the induction.

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This is indicated on the diagram by the curve becoming nearly horizontal. The current is then decreased step by step and the induction measured, until the current drops to 0, represented by the upper part of the curve crossing the middle line. The experiment now proceeds by sending a current round the conductor in a reverse direction, and increasing its strength step by step, taking measurements of the induction as before until the saturation point is again reached in the reverse direction; the current is then reduced again step by step till the curve returns to the middle line. This operation is repeated several times until the curve settles down to a steady cycle, and this steady curve is shown on the diagram.

The other diagram, Fig. 2, gives curves of permeability, or the ratio $\frac{B}{H}$ deduced from the curves in the first.

Looking now at the curves it will be seen that the magnetising force H produces in cast-iron a much smaller induction than in wrought-iron or in steel; further, that the amount of induction B resulting from a given magnetising force H varies at the higher parts of the curve according to preceding magnetic condition in the cast-iron very much more than in the wrought-iron or steel. That wrought-iron and steel are capable of magnetisation to a much higher degree, and again, that the energy required to produce a reversal of magnetisation in cast-iron is much greater than in steel or wrought-iron, all these peculiarities are disadvantageous, and therefore the use of cast-iron for the parts of the motor subject to reversals of magnetisations has practically disappeared, and in all other parts has almost completely given way to wrought-iron or steel. The steel has the special advantage that, while it has magnetic properties even superior to wrought-iron, it can be cast into any desired shape and still retain its magnetic properties.

These considerations led to the adoption of steel for the magnets and case—the case also forming part of the magnetic circuit—of the motor in question.

B in the curves representing the induction per square centimetre of the metal, it will be seen that for a given total induction the steel need be much smaller in section than cast-iron, and H, repre-

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senting the magnetising force per centimetre length, the reduction of magnetising force and consequent reduction of space for the conductor to carry the magnetising current, leads to a still further advantage.

It will thus be seen that the use of steel has not only increased the efficiency of the motor by reducing the necessary magnetising force, but by reducing the size and labour in tooling has also reduced the cost of production, while the use of a short air space has made it possible to entirely enclose the motor without seriously increasing its weight. The enormous advantage of this will be at once apparent. Dust, damp, and explosive gases are entirely excluded from the working parts, while the increased radiating surface seems to compensate entirely for the less efficient circulation of air.

There seems every reason to expect that this machine has an important future in its application to mining.

Mr A. W. STEWART thanked Mr Mavor for the very lucid description he had given of his motor, especially to those who did not know much about the way the torque was given to the armature. He thought the description was one of the clearest he had ever heard. He asked Mr Mavor if there was no trouble from sweat or moisture inside the shell. In a changeable temperature like a coal pit, a good deal of moisture would be dropping about the connections, and would develope short circuits and other troubles. He would also like to ask him if he had tried anything in the way of alternating currents as applied to this motor. He understood that Mr Brown, of the Oerlikon Works, had designed and had actually motors working now, called three-phase motors. These motors had no brushes or commutators, and worked with a very high efficiency, and so got over the difficulty that every one who had worked with commutators must know about—the sparking of the brushes and the wear of the commutator. This was certainly a big step in advance to do away with commutators. Any one who had been working with them knew that not only the wear of the

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commutator was a great nuisance, but also the breaking of the connections of the coils on the armature to that commutator. They gave incessant trouble in the best designed motors.

Mr SAMUEL MAVOR said that with regard to the efficiency of transmission of power for colliery working, the efficiency might be a very important point, but there were other considerations which were often a great deal more important than efficiency. The difficulty and danger of carrying steam down a pit and along the roads were very great; the loss was also very great, and there was always the trouble of keeping the joints tight, with the result that leaky joints were always in these pipes, and the roads were kept more or less choked with steam. The electric motor required less attention than the air or steam motors, so that in a pit where rope or steam transmission was used there were often small pumps where two, or three, or four men were working by hand, simply because the cost of the steam or rope transmission to those distant pumps would be so very great. One man paying the electric motor a visit on each shift for oiling was quite sufficient to keep the thing in good order, so that he might point out that although the efficiency for comparatively short transmissions might not be so high as some might expect, other considerations were frequently so important as to lead to the adoption of electrical transmission.

Mr JOHN BARR asked Mr Mavor to state whether there was a small proportion of carbon in the field magnets, whether they were cast-steel or hammered afterwards. The drawing showed a double brush where the spindle worked through the cast-iron casing, and he presumed it was made thus for replacement. He thought the efficiency of these motors was a very important point. It would be interesting if Mr Mavor could tell them what ultimate efficiency he got, say from a set of pumps driven by a motor in practical every day work, *i.e.*, taking into account friction of steam engine dynamo heads, motor, and pumps, leaving out the friction that might occur between the pump and the surface.

The discussion was adjourned to next General Meeting.

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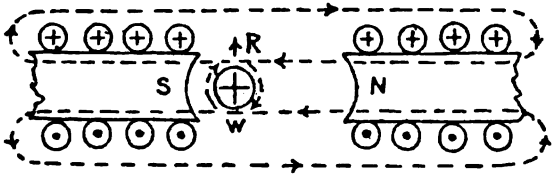
The discussion on this paper was resumed on 22nd January, 1895.

Professor JAMIESON said, that from the statements made by Mr Mavor, it was evident that he regarded electricity as a substance, and not as a "mode of motion." With this view he could not agree. With regard to the two lower diagrams, on page 77, he must confess that they did not afford such a clear idea of the actions involved in the working of dynamo-electric motors as they would had they been properly drawn. As an endeavour, however, to improve the last of these figures, he made a sketch upon the black-board, of which the following is a representation:—*



To Illustrate the Action of Dynamo-Electric Motors.

(1.) We have here the N and S poles of the field magnets properly marked.

(2.) The field magnet cores are shown as if broken off short, or discontinued.

(3.) The direction of the flux of the magnetic field is shown by dotted lines and arrows instead of full lines, since these are merely stress lines, and not visible parts of the machine.

(4.) Where the current is coming towards the observer, the circles indicating the section of the conductors have arrow-points at their centres; and where the current is flowing from the observer, the circles have a cross, or an arrow-tail to indicate that direction of flow. This system of indicating the direction of currents in wires is very useful.

* The substitution of crosses for dots in lower part of diagram, as issued in monthly Transactions, was a printer's error, and has been corrected for Volume issue.—ED.

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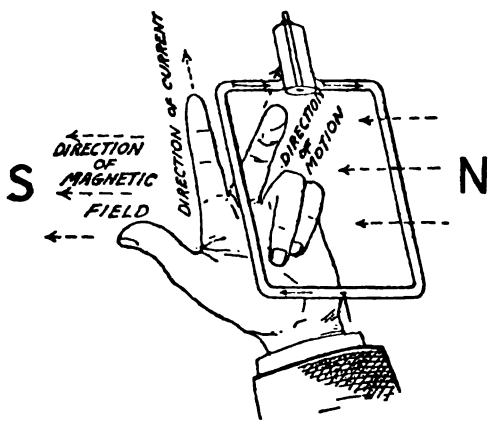
(5.) The resultant direction, R, of the motion of the current-carrying-wire, W, is indicated by a dotted line and an arrow-head.

He said that it was of great importance, that the mechanical engineer should obtain a thorough grip of the action of dynamos and motors. Consequently, he had thought fit to supplement Mr Mavor's remarks, and to add this general rule, which provided an explanation of all interactions between magnetic fields, viz.:—"If a magnetic body be placed in a magnetic field, and be free to move therein, it will invariably tend to place itself so that the direction of its field coincides with that of the field in which it is placed." By a magnetic body is here meant any body that has magnetic force associated with it; for example, a magnet, or a current-carrying-wire or coil. A still clearer understanding of the above law, and of the previous illustration, would be obtained from an examination of his left hand rule or aid to the memory. By pointing the thumb of one's *left* hand in the direction of the field, the fore-finger in the direction of the current,



Left Hand Rule for Motors.

then the outstretched middle-finger would indicate the direction in which the current-carrying-wire tends to move, as shown by the

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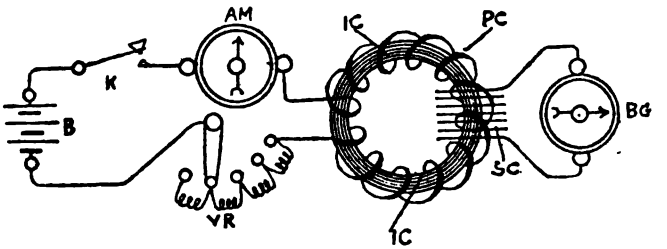
above and previous figures. Mr Mavor had drawn their attention to the very close coincidence between the results of independent tests by Professor Ewing, in the Cavendish Laboratory, Cambridge, and himself (Professor Jamieson) of the new "dynamo-magnet cast steel," as produced at the Imperial Steel Works, Sheffield. It might be both interesting and instructive to indicate by a diagram and short description how these results were obtained.



Connections for Permeability Tests.

Index to Parts.

I C	represents	Iron (or Steel) Core	K	represents	Key.
P C	„	Primary Coil.	B	„	Battery.
S C	„	Secondary Coil.	V R	„	Variable Resistance.
A M	„	Ammiter.	B G	„	Ballistic Galvanometer.

The steel to be tested was cast and turned into the form of a ring. It was then wound uniformly all over with 2221 turns of an insulated conductor, or primary coil, P C, and over one part of this primary with 100 turns of wire for a secondary coil, S C. The primary winding was placed in circuit with a battery, key, ammeter, and variable resistance; whilst the secondary coil was joined to a ballistic galvanometer, which gave a throw proportional to the quantity of electricity that passed through it, and hence also proportional to the magnetic induction evoked in the metal ring, by the current passed through the primary coil. The results obtained were plotted upon squared paper, as per the following figure, where the horizontal distances, O H_1 and O H_2, indicate the strengths of the field pro-

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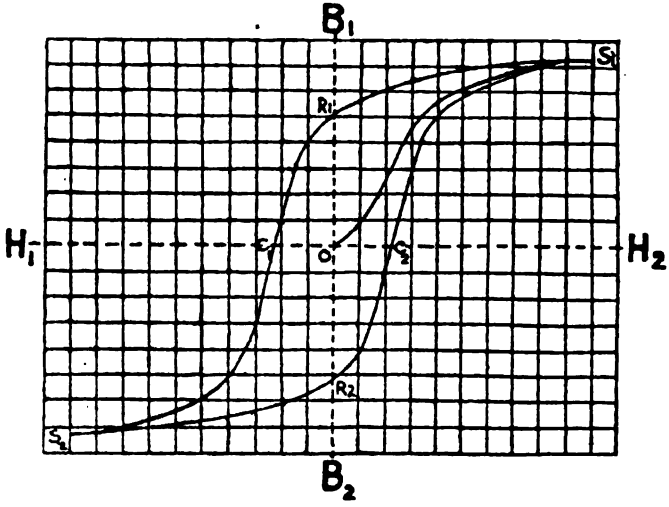
duced by the various currents passed through the primary coil; and the vertical distances, O B_1 and O B_2, indicate the corresponding magnetisation induced thereby in the steel ring.



Curve showing Magnetisation, Retentivity, Coercive Force, and Hysteresis.

If this ring had never been magnetised, or if it had no residual magnetism, then the first observation would be plotted very near O. The current in the primary coil was then increased by sudden steps, and the deflections of the ballistic galvanometer noted, when it was found that the magnetism increased, as represented by the line O S_1, until saturation took place. On reducing the current to zero, the magnetisation fell from S_1 to R_1. Hence O R_1 represents the *Retentivity* of the specimen for magnetism. The current was then gradually increased in the opposite direction, until the point C_1 was reached, when no magnetism was observed in the ring. Therefore, O C_1 represents the *Coercive force*, or that force which had to be applied to the ring to clear out the magnetism of retentivity. Still further increasing the current, the specimen became saturated on reaching S_2. On reducing the current again to zero, a point R_2 was reached, giving O R_2 for the retentivity on the return side of the

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cycle, and O C_2 as the corresponding coercive force. Altogether, an area of work, $S_1 R_1 C_1 S_2 R_2 C_2 S_1$, was obtained, called the area of *Hysteresis*. This term means the lagging of the magnetic induction behind the magnetising current. According as this area is small or large it indicated whether the material is good or bad for the purpose of alternate current transformer, or dynamo armature cores, or wherever such material had to be placed in a rapidly changing magnetic field. It was a pity that Mr Mavor had not given them a description of how the armature of this new and interesting mining motor was wound. He might also have told them somewhat of its efficiency and capabilities for different kinds of work, and whether he had found it necessary to paint the same with some non-hygroscopic substance in order to prevent the accumulation of moisture inside the closed steel case.

Mr MacWhirter said there were a few points that he would like to bring up in connection with the discussion on this paper, and the first one was Mr Mavor's idea of the electrical whirls. Of course, it was quite evident that Mr Mavor did not for a moment mean to put this forward as being founded on fact. He would be very much surprised if he did. It had always been a proverb well known to most of them that nothing produced nothing. Mr Mavor spoke about magnetic whirls, and if there were such things at all it stood to reason that there must be some energy or force expended in the continuance of these whirls. So long as they dealt with an electro-magnet, it might be said that there was a continual waste of energy going on from the moment the current was switched on till it stopped, but if they took up a permanent magnet they had the same magnetic conditions, and if in the one case they had these whirls they must have them in the other. They knew, as a matter of fact, that there was no waste of energy going on in a permanent magnet from the time it was made till the future periods. He really thought that Mr Mavor ought to have pointed out these clearly. On page 78 there were these words:—"There is no doubt that experience has shown the most satisfactory method of mounting the conductors is to place them in channels in the iron core, as

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shown in the diagram. (See Plate V.)" The fact of the matter was that, with the exception of Messrs Mavor & Coulson and one or two other firms, out of all the makers of dynamos in the country he did not suppose there were more than two or three per cent. of the dynamo makers who would ever think of embedding their conductors in iron cores. Many of those who did this years ago had since abandoned it altogether. In speaking about the winding of the armature, it was a very nice and neat arrangement, and Mr Mavor told them that by the arrangement carried out they had no trouble about insulation. Looking at it as it was, a drum winding with several turns in each slot, there was no doubt at all in his mind that there must be a very great difference of potential between the coils which came close together. For example, in this motor there were 440 volts, and of course the coil on the one side must come into immediate contact with the coil in the other side where that difference of 440 volts existed. He said that means were taken to give extra insulation at that point, and he would like to know if it was not the case that the two wires came exceedingly close together, because the least drop of moisture due to sweating or other causes would at once do away with any insulation that could be applied. Another matter was the very small air space. On page 80, Mr Mavor said, "The effect of this shortening of the air space would be at once evident from what had been said about the magnetic field—the intensity of the magnetic field, or group of magnetic whirls, set up by the conductors wound on the field magnets, depending on the nature of the substances which form its path," and he also said, "Formerly, considerations in connection with sparking fixed a limit to the air space or gap between the magnets and armature, so that this could not be reduced to the dimension otherwise desirable. The use of this device has enabled us to reduce the air space to the very small dimension shown in the diagram." His (Mr MacWhirter's) experience of small air spaces had been altogether different from that. There had always been a trouble with the heating in such armatures. He had no doubt with perfect lamination they might get rid of the heating even in such

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small space as Mr Mavor mentioned, but that was a matter of £ s. d. It was a question of whether that would be the cheapest way of doing it. Coming to page 81, Mr Mavor told them that "In the old days, cast-iron was the material principally used for field magnets. The researches of Dr Hopkinson and Mr Gisbert Kapp demonstrated, without doubt, that dynamos ought not to be made of cast-iron, and wrought-iron for many succeeding years held the field." Speaking for himself, he had certainly never dreamt for a moment that the researches of Dr Hopkinson and others who had worked in that way had ever made such a demonstration. They showed plainly that if they used cast-iron they must use more of it, and it became a question of pounds, shillings, and pence to use wrought-iron or cast-iron. The ring which Professor Jamieson showed them with which his magnetic experiments were carried out was first made by Faraday, who had done so much good work on magnetic induction. When touching on the curves of magnetisation with Edgar Allan's steel and grey cast-iron, it was said that they should have three times as much of the one as the other, but his (Mr MacWhirter's) firm knew that in practice with the quality of cast-iron which they used, and which was a good deal better than Mr Mavor had given in his paper, they got no benefit by going beyond 1½ times—that was to say, 50 per cent. increase in section. They found that that was a very suitable ratio. There was no doubt that Allan's steel was excellent, but lately they had made test dynamos, and he had a set of figures which were tested in the West of Scotland Technical College nearly three years ago, and specimen bars were sent to Professor Jamieson without giving any data whatever relative to these bars. He did not say whether they were cast-iron or wrought-iron. And it was very gratifying to find, and he thought it should be known with reference to the work done in the College, that the figures returned to him by Professor Jamieson were practically identical with the figures obtained by his own assistants in their testing room. In reference to the steel, there was a question of cost. That was a very important question. They could get a very high quality of cast-iron in Scotland at about £7

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per ton. If they wanted to get pure iron cast in Sheffield it might cost them £18 to £24 a ton, so that in coming to a decision as to which they should use, these facts had to be borne in mind. He was sure that it was very gratifying to see such a compact and thoroughly well protected machine as Mr Mavor had brought before them. He had heard a gentleman the other night say, that he would not be satisfied with a dynamo till a hose could be played over it. He had very great pleasure in saying, that it almost entirely met the above conditions.

Mr MAVOR, in reply, took Mr MacWhirter's remarks first, because he thought they were the most important. He had to thank him for the way he had spoken about his motor. It showed a very commendable spirit. With regard to the electrical whirl question, he might say that he was not an original investigator, or original thinker, and these matters of terminology were largely borrowed from Professor Lodge, but he largely concurred with him on these matters, and he had no doubt that electricity was not a mode of motion—it was a substance. With regard to what Mr MacWhirter said about the energy expended, he did not believe that any energy was necessary to keep a substance in motion, unless something hindered its motion. They might as well ask why the earth was whirling round. No energy was expended in keeping it whirling. When they started a current, energy was expended in setting up the whirls, but, when any further energy, it was expended in heating the wire, and not in keeping up electric whirls. With regard to the slotted cores for the armatures, it was a matter of opinion whether that was the best way of making a machine; and although nearly all English makers differed from him, in America it was a very common practice indeed. Some of the largest makers used it, and in Germany, Siemens and Halske used it almost universally; while in Buda-Pesth, Ganz & Company, and in Oerliken, Brown used this style of winding the wires on the core almost universally. At last meeting there were some questions asked by Mr Stewart, who spoke of the three-phase motor of the Oerliken Company. That was a very excellent machine, but it had not found favour in this country,

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because it was a very expensive machine for the work it did. In many cases these objections were superseded by the advantages to be gained by having no commutator on the machine. Mr Barr had asked whether there was any carbon in the field magnets. The stuff was called steel because it was made by the steel process, but the aim was to leave nothing but chemically pure iron. He did not understand Mr Barr's question about the spindle working through the cast-iron casing, but he had brought an actual machine to show how it was constructed. It was a small 3 horse power, and the one described in the paper was nearly 50 horse power. He had to thank Professor Jamieson for the alteration in his diagram. The cross was an error, and should have been a dot.* He had much pleasure in renewing his acquaintance with Professor Jamieson's lectures. He had sat under his lectures fifteen years ago, and he enjoyed them now as much as ever. He had to thank him for his criticism.

The PRESIDENT said now that the electric disturbance had passed over, he proposed a vote of thanks to Mr Mavor for his paper. It had been thought convenient to postpone the discussion on Mr Thomson's paper till after the reading of the paper by Professor Watkinson, and to take the discussion of these two papers together, if Mr Thomson had no objection.

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* The substitution of a cross for a dot was a printer's error, Mr Mavor's sketch diagrams, from which zincotype figures were made, having the crosses and dots in correct position.—ED.

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On "Results of Evaporative Tests on Land Boilers."

By Mr GEO. CARRUTHERS THOMSON, F.C.S.

(SEE PLATES VI., VII., AND VIII.)

Held as Read 18th December, 1894.

THE questions of smoke abatement and the combustion of coal have been brought prominently before the public of late, and, if only from a sanitary point of view, are of great importance and special interest to the dwellers in this city and its suburbs.

It seems passing strange that, while the consumption of coal in our factories and workshops is large and constant, and, while any number of patented methods and appliances for effecting a saving in the quantity of fuel used have been tried again and again, carefully conducted experiments, to find the actual work done by the fuel under consumption, have been conspicuous by their rarity or total absence.

In looking over the Transactions of the Institution since the first session, I can find no detailed trials of the evaporative power of boilers, or analyses of the fuel used and the gases given off, nor am I aware that any reports have hitherto appeared in the ordinary engineering journals, of a sufficiently practical nature to be of general use to factory owners in this district.

When the Glasgow Exhibition of 1888 was being organised, strong efforts were made to have a series of experiments carried out on the boilers necessary for the machinery in the Motion Exhibit, so that their evaporative power, while working with various smoke abating or consuming appliances, could be thoroughly tested.

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These efforts were without avail, and a good opportunity was lost. Subsequent to this date a Smoke Abatement Association was organised in Manchester, which carried out a number of tests, the results of which have not been published as yet, but I understand they will be made public shortly.

Later still, on the 29th October, 1890, the Glasgow and West of Scotland Smoke Abatement Association was formed, and a number of trials carried out, and a report issued in August, 1893, containing the results of a few of the trials and the recommendations of the executive committee of the Association.

Having carried out the trials for this Association, I considered that the results obtained were of sufficient value from an economic point of view to permit of their being laid before the members of this Institution.

Along with these results I have also given those of other trials carried out by me after the work of the Association ceased.

In order that the results of these trials should represent as nearly as possible what is obtainable under usual working conditions, the following points were kept in view, viz. :—

That the boiler under trial should be doing its regular work.

That the fuel should be of the average quality used at the factory.

That the regular fireman should pursue his usual practice in firing, cleaning, etc.

That it be intimated to the fireman that a note of the smoke emitted from the chimney would be made.

When considering what length of time the boiler should be under trial, it was necessary to take into account the varying nature of the work in different factories, and the elimination, so far as possible, of sources of error in the measurement of materials used, atmospheric changes, state of fires, change of firemen when night and day work was carried on, and as far as possible the avoidance of any disturbance of the usual working conditions, as well as the length of time the observer and assistants could remain in good working form.

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A full review of all these considerations determined me to fix on ten hours as being the best time for a trial, as beginning at 7 a.m. and stopping at 5 p.m. gave time for fixing instruments in position, and seeing to the fires being in good condition, water at a good height in gauge glass, coals weighed, and everything ready to begin, while the time after 5 p.m. was taken up in weighing ashes, putting up samples of coal, weighing back any coal left over, and leaving things generally in order, so that usually twelve to thirteen hours were taken up on each day's run.

In order to carry out these trials, it was necessary to arrange in the first place that the boiler, with its fittings and connections, be put in such a state, that the various instruments to be used for ascertaining temperatures, measuring water, collecting gas samples, etc., could be placed in such positions that the necessary observations could be made, without interfering with the ordinary working of the boiler.

After the various connections had been made, a trial run was carried out to test if everything was in good working order.

To test the regular work of the boiler, and to ensure that the special trials were of a representative character, and such as could be obtained in every work, a control run or runs were carried out.

These control runs were carried out in every way the same as the special trials, with the exception that the coals and gases were not sampled for analysis, and that the observations were only taken every hour, instead of every half-hour as in the special trials, and it was only when I was satisfied with the working of these control runs, that I proceeded with the special trials recorded here.

In trials Nos. 1, 2, 3, and 4, these control runs extended over a continuous period of seven days and seven nights, observations being taken hourly from 6 a.m. till 6 p.m., and one observation at 10 p.m. in addition.

The special trials were taken on one of these days, and lasted as nearly as possible ten hours, during which time observations were taken every half-hour, and coals and gases sampled for analysis.

In the remaining trials the control runs only lasted one, two, or

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three days, or just sufficiently long to allow the assistants to thoroughly understand the duties devolving upon them, and as soon as this was the case the special trial was taken.

The results of these control runs agreed very closely with those obtained in the special trials, and were within the limits of observation errors.

DETAILS REGARDING INSTRUMENTS AND THE CONDUCTING OF THE TRIALS.

Chimney.—The height of chimney is given as above the level of furnace bars.

Barometer.—The readings were taken from a tested aneroid barometer, graduated to $\frac{1}{10}$ of an inch.

The direction of the wind was determined by means of a compass, and its strength, as well as the state of the weather, was noted.

Steam Pressures.—The steam gauges on the boilers were each tested and compared with a standard steam pressure gauge of Messrs Schäffer & Budenberg's manufacture, and corrections made when necessary.

Analyses.—The analyses of the fuels were carried out by Mr R. R. Tatlock, city analyst, who is also responsible for the analyses of the gases in Nos. 16 and 17. Mr Lindsay Burnet, Govan, analysed the gases in all the other trials.

Carbon Value.—This represents the value in pure carbon of 100 lbs. of the fuel used in each trial.

Fuel.—The system of checking the weight of the coals supplied varied according to the circumstances of the works, and the weighing machines in each case had been tested shortly before for this purpose.

Where the fuel was delivered in trucks, these were weighed

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emptied, and the empty truck weighed, and the difference was taken as the weight of fuel.

In the majority of cases the fuel was delivered in carts, and the same method of weighing adopted as with trucks, while in a few cases the fuel was weighed in barrows in 2 cwt. lots.

The ashes were weighed in carts or barrows as was found most convenient.

Sampling.—In sampling the fuel for analysis, a shovelful was laid aside every hour, and just before the close of the test these were well mixed and quartered, half thrown aside, again mixed and quartered, and so on till only a small portion was left to be taken for analysis.

This method of sampling the fuel is the same as that adopted by the Society of Engineers in Germany. See "Thurston's Manual of Steam Boilers," page 486.

In sampling the gases, the samples were taken just before reaching the damper, and were drawn in glass stoppered sampling flasks, over a concentrated solution of common salt, and were so taken as to obtain a fair average of the gases passing into the chimney.

Temperatures.—The temperatures of the air, and of the feed water were ascertained with mercurial thermometers, which had been checked by comparison with a "Kew" standard thermometer.

The temperature of the exit gases was taken before passing the damper, the instrument used being in some cases a "Murrie's" water pyrometer, in others a "Bailey's" pyrometer, and in the majority of cases a mercurial thermometer—known as a Jena thermometer, and manufactured by Messrs Schäffer & Budenberg, in which the space over the mercury was filled with nitrogen gas under pressure—was used, so that temperatures up to 950 degrees Fahr. could be noted with accuracy.

Where the temperatures were higher one of Messrs Schäffer & Budenberg's mercury thalpotassimeters was employed, giving readings up to 1400 degrees Fahr.

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The readings from each of these pyrometers were checked by the use of a "Fischer's" water calorimeter (see Transactions, Vol. XXXV., page 148), which gave concordant results with the two last mentioned instruments—the Jena thermometer and thalpotassimeter; but the other two instruments named required their readings to be corrected.

Anemometer.—The speed of the air in feet per minute entering the furnaces below the firebars was taken with an ordinary "Biram" anemometer, either 4 inches or 6 inches diameter, according to the amount of room below the furnace bars.

A "Davis" self-recording anemometer was used in test No. 7, but owing to an accident occurring to it the readings are not given in the table. After repair it was used in tests Nos. 5 and 6.

I preferred using the "Biram" instruments, as they gave indications ranging over any period of time desired, while the "Davis" instrument only gave the speed at the second at which it was tried.

Draught.—The power of the draught in flues and chimney measured in inches of water was obtained by using an ordinary U tube half filled with water, and connected by a flexible tube to the flue or chimney. The draught in the flues was measured alongside the pyrometer, and the chimney draught taken either in the chimney itself, or in the main flue close to the base of the chimney.

Water Measurement.—In trials Nos. 1, 2, 3, and 4, the feed water was measured by passing through a Siemens rotary hot-water meter, so placed as to be as little affected as possible by the working of the donkey feed pump.

In Nos. 12, 13, 14, and 15, a Worthington water meter was employed, to measure the cold water into the tank, from which the injector or feed pump drew its supply for the boiler, the height of water in the tank being noted, and brought to the same height at the end of the trial.

In Nos. 5, 6, 7, 8, 9, 10, and 11, two tared tanks, with suitable connections, were used, a Worthington duplex pump being em-

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ployed, except in Nos. 10 and 11, in which a duplex pump, by Messrs Carruthers & Co., Polmadie, was used; one tank being filled while the other was being emptied by the pump.

In Nos. 16 and 17 the cold water from the main was run into the "tared" tanks, and from them measured into the tank which supplied the injector, the overflow from injector at starting being returned to the tank which supplied the injector, and in which the level at beginning and end of trial were the same.

The temperature of the feed water in the first four trials was taken every half-hour in the tank from which the pump drew its supply.

In Nos. 5 to 11 inclusive the temperature of each tank of water was taken, while in the remaining trials the temperature was taken after passing through the meter or measuring tanks, and also between the injector and boiler.

Cleaning Fires.—In the hand-firing trials the fires were cleaned in the usual sense of the term, and conducted at each work according to the regular practice of the fireman.

All the mechanical stokers being fitted with self-cleaning bars, the clinker and ashes were drawn out from the bottom of the furnace when necessary.

Working of the Boilers.—In trials Nos. 3 and 4 the makers of the mechanical stokers tested supplied men to work the boilers, and were assisted by the regular attendant.

In all the other cases the firing was done by the regular attendant, and in the cases of the other mechanical stokers the machines had been in use for a considerable time, and were in charge of the usual attendant.

In No. 10 a breakdown of some of the machinery immediately after the beginning of the trial reduced the load considerably.

In Nos. 12 to 17 inclusive the boilers were run at two rates of speed.

The boilers were worked at full average daily work, with the

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exception of Nos. 12, 15, and 17, which were purposely wrought at a lower speed.

Trials 1 to 7 inclusive and No. 11 took place in calico printing establishments, where the demand for steam was as great and intermittent as is likely to be met with.

In Nos. 8 and 9 the steam was used for driving the engines of a cotton spinning mill and heating purposes.

In No. 10 the boiler supplied steam to a compound engine driving the machinery in a paper mill.

In Nos. 12 and 13 the boilers supplied steam to the engines and steam hammers of an engineering establishment.

In Nos. 14 and 15 the boiler supplied steam to several foundry cranes, steam hammers in smithy, etc., in an iron foundry.

In Nos. 16 and 17 the boiler formed part of a range which supplied steam to a rolling mill plant in a steel work.

Priming.—There was no priming in the usual sense of the word, and the water in the gauge glasses was practically free from disturbance in every case.

The actual percentage of moisture in the steam was not experimentally determined, as after a careful review of all the different methods and apparatus proposed for the purpose of determining this quantity, I considered the sources of error so great and so easy to arise, that I decided they were entirely out of place in a boiler trial under the usual working conditions.

Factor of Evaporation.—This is the figure obtained when reducing the results of boiler trials to the common standard of evaporation from and at 212° Fahr., and is obtained thus:—Let

H = Total heat of steam in British thermal units at temperature corresponding to the pressure, calculated from zero Fahrenheit.

t = Temperature of feed water in degrees Fahrenheit.

W = Lbs. of water evaporated in test per lb. of fuel from feed temperature.

W_1 = Equivalent evaporation from and at 212° Fahrenheit.

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L = Latent heat of steam = 966.

Q = Factor of evaporation.

$$Q = \frac{H - t}{L} \text{ and } W_1 = W \times Q.$$

Calorific Value of Fuel.—The calorific value of the fuel as given in the table, was arrived at by calculation from the analysis, and was not determined experimentally. As it was desirable that the results should be comparable with those obtained by the Manchester Smoke Abatement Association, I asked Professor Kennedy if he would kindly give me the number of thermal units he used for carbon and hydrogen, in calculating the results of the trials he carried out for them. He did so, and the values are 14,540 for carbon and 52,200 for hydrogen. This is practically the same as Dulong's formula, which is used by the Society of Engineers in Germany, for calculating the heating power of fuel from the chemical analysis.

My reason for not determining the calorific value experimentally was, that the coals were burnt as they came to hand, whether wet or dry, and if the coal was burned in a calorimeter it required to be perfectly dry, or the experiment could not be carried out satisfactorily.

A comparison of the results obtained by P. Mahler* in his researches on the calorific values of fuels by actual experiment, with the results given by calculation from the chemical analysis, shows that the formula of Dulong agrees more closely with these results than the formula proposed by Mahler.

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* See Bulletin de la Société d'encouragement pour l'industrie nationale, tome VII., page 319; e errata pour son memoire, p. 744—anno 1892.

Also, Tests of the Heating Power of Coals, by William Kent, in "Mineral Industry," Vol. I., page 97—year 1892.

Formula by Dulong:

$$\frac{1}{100}\left[8080C + 34500\left(H - \frac{O}{8}\right)\right] = \text{heating value.}$$

Formula proposed by P. Mahler:

$$\frac{8140C + 34500 - 3000(O + N)}{100} = \text{heating power.}$$

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Dulong's formula is based upon the heating values of the two elements, carbon and hydrogen, and assumes that the oxygen in the fuel renders unavailable for heating purposes one-eighth of its weight of hydrogen, while Mahler's proposed formula takes account of the nitrogen, and introduces an empirical constant 3000.

Smoke.—In several cases the smoke emitted during the trial could not be observed, owing to several other boilers being connected to the same chimney, and in these cases no observation was taken.

In the remaining cases the boilers tested were either connected to a single chimney, or, if other boilers were connected to the chimney, no smoke issued from it.

The quality of the smoke emitted from the chimney was classed as dense, medium, faint, or no smoke, and the average amount per hour of each description given in minutes.

Practical and Theoretical Heating Power of Fuel.—This was calculated from the proximate analysis of the fuel by means of Playfair's formula.

Duration of Trials.—The time given in table represents the actual steaming time, after deducting meal hours or time during which no steam was drawn from the boilers.

DETAILS OF TRIALS.

The principal details of each trial are given in the table and diagrams, and I shall now only give the details required to make them complete, and which could not so well be placed in tabular form.

Before beginning a trial all the instruments were placed in their proper position, the ashes drawn from the furnace tubes, the stokehole cleared of coal and made ready for the weighed quantity being laid down, the height of the water in the gauge glasses noted, the measuring tanks for the feed water full, the fires in good order, and their condition carefully noted, so that the trial should be

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finished with the fires in the same condition as nearly as possible, and when all was in order the trial was begun, as near seven o'clock as possible.

No. 1.—This was one of two boilers close to base of chimney, the flue to chimney being 13 feet long and 3¾ square feet in area, the damper being close to the chimney, and full open during the trial. The gases from furnaces went under the boiler, and split along sides to main flue. Trial began at 7 a.m. and ended at 5 p.m. without stoppage. Steam varied from 30 to 43 lbs. pressure. Fires cleaned at 9-30 a.m. and 1-30 p.m. Gas samples drawn from 12-45 till 1-10 p.m., and 4-27 to 4-48 p.m. Fires stirred between each firing. Firebars 6 feet 6 inches long. No air admitted at furnace door—only at bridge, and did not evaporate so much water as the boiler alongside, which had nothing extra fitted to it.

Average draught at front of boiler in side flues was ·24 ins. w.g.

No. 2.—These three boilers were in the centre of a battery of eight boilers, and were distant about 50 feet from chimney. United damper area 10·5 square feet. Approximate area of main flue 10·68 square feet. Dampers full open during trial. Gases from furnaces travelled the same as in No. 1.

Trial began at 7-10 a.m. and closed at 5-10 p.m. without stoppage. Steam varied from 25 to 37½ lbs. pressure. Fires cleaned at 9-30 a.m. and 1-30 p.m. Gas samples drawn from 11-56 to 12-19 noon, 12-59 to 1-14 p.m., 1-50 to 2-1 p.m., and 3-44 to 3-58 p.m. Fires stirred between each firing. Bars 6 feet 6 inches long. The draught was poor (see table) owing to smallness and bad condition of main flue, and an obstruction in the main flue between these boilers, and those immediately to the left-hand side, where the draught was very good.

Average draught at front of boiler in side flues was ·18 ins. w.g.

No. 3.—The same boilers as in No. 2. Dampers, area 10·5

Note—w.g. = water guage.

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square feet, full open during trial. Steam varied from 27 to 37 lbs. pressure.

Trial began at 7-8 a.m. and closed at 5-8 p.m. without stoppage. Ashes drawn at 9-30 a.m. and 2-30 p.m. Gas samples drawn from 12-28 to 12-45 p.m., 12-50 to 1-12 p.m., 1-18 to 1-43 p.m., and 3-53 to 4-20 p.m. 32 steam jets, each $\frac{1}{16}$-inch diameter in $\frac{3}{8}$-inch pipe, in each furnace, going all the time to cool the furnace bars. Fires levelled once per hour. Bars 5 feet 3 inches long.

Average draught at front of boilers in side flues was ·2 ins. w.g.

No. 4.—Same boilers as in Nos. 2 and 3. Damper area during trial 8·5 square feet. Steam varied from 29 to 39 lbs. pressure.

Trial began at 7-18 a.m. and closed 5-3 p.m. without any stoppage. Ashes drawn at 9-30 a.m. and 2-30 p.m. Gas samples drawn from 12-29 till 12-45 p.m., 12-52 till 1-13 p.m., 1-21 till 1-40 p.m., 3-33 till 3-41 p.m., 3-49 till 4-18 p.m., and 4-19 till 4-38 p.m. Steam admitted over each fire by an $\frac{1}{8}$-inch jet at end of $\frac{1}{2}$-inch pipe, and at back of grate below bars by 20 jets $\frac{1}{16}$-inch diameter, kept constantly going. Firebars 4 feet 8 inches long.

The boilers in these four trials were all covered with bricks, and enclosed in a house. The centres of boilers were 9 feet 6 inches apart, and the side flues were rather contracted.

The feed water in these four trials was heated in large tank by waste steam blowing into it.

In these four trials steaming was easier at time of cleaning the fires.

Average draught at front of boiler in side flues was ·2 ins. w.g.

No. 5.—This was one of a range of 7 boilers, and with the boiler next to it had a separate chimney, and during the trial the other boiler was off duty. The gases from furnaces were split along sides of boiler, and went back under boiler to main flue.

Damper close to boiler with 5 square feet area, and full open during trial. Main flue 5 square feet area for 15 feet from damper, and then for 61 feet to chimney the area was 15·5 square feet.

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Trial began at 7 a.m. and closed at 5 p.m. Continuous steaming. Steam pressure varied from 56 to 67 lbs.

Temperature at end of boiler in oval flue at 11 a.m. was 1030 deg. Fahr., and at 4-30 p.m. 1100 degrees Fahr. At side flue, at front of boiler, at 11-30 a.m. the temperature was 730 degrees Fahr., and at 1-10 p.m. 765 degrees Fahr. Gas samples drawn from 12-42 till 1 p.m., and from 3-52 till 4-7 p.m. Firebars 5 feet 9 inches long. Boiler cleaned inside and outside on the 18th September, 1891. Ashes drawn at 12 noon and 5 p.m.

Average draught at front of boiler in side flues was ·44 ins. w.g.

No. 6.—This boiler was to the right of No. 5, and connected to same flue and chimney.

Damper full open during trial, and of same area; length and area of flues the same, and the gases, after leaving furnace, travelled below boiler, and split along side to main flues.

Trial began at 7 a.m. and closed at 5 p.m. Continuous steaming. Steam varied from 55 to 69 lbs. pressure. Temperature at back of boiler flue at 12 noon was 1200 degrees Fahr., and at 3-55 p.m. 1170 degrees Fahr., while at side flue, at front of boiler, at 10-30 a.m. was 920 degrees Fahr., and at 3-30 p.m. was 915 degrees Fahr. Ashes drawn at 12 noon. Gas samples were drawn from 12-12 to 12-29 p.m. and 4-7 till 4-20 p.m. Fire bars 5 feet 9 inches long. Boiler cleaned inside and outside on 6th August, 1891.

Average draught at front of boiler in side flues was ·375 ins. w.g.

No. 7.—This boiler was the same as No. 6. Damper full open during trial.

Trial began at 7 a.m. and stopped at 5 p.m. Continuous steaming. Steam varied from 52 to 68 lbs. Ashes drawn at 12 noon. Gases sampled from 11-26 to 11-50 p.m., 1-27 till 1-47 p.m., and from 3-55 till 4-7 p.m.

The slice was used once per hour in this and the two preceding trials, to keep the clinker from fixing to the bars, and every time this was done about five minutes faint smoke issued from the chimney.

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The boilers in this range were covered by non-conducting composition, and were protected by a roof against the weather.

In trials Nos. 5, 6, and 7, steam is used to cool the bars in the stokers, and is admitted into each furnace by 9 jets, $\frac{1}{16}$-inch dia.

Average draught at front of boiler in side flues was ·42 ins. w.g.

No. 8.—This boiler was the right hand one of a range of eight, of which seven were working—the boiler next trial boiler being at work. Boiler dampers kept full open during trial 10½ square feet area, discharging into the main flue area at boilers 42 square feet, and length to chimney about 70 feet, and 49½ square feet area. Swivel damper in main flue not full open. Gases from furnaces travelled below boiler and split along sides to main flue. Trial began at 7 a.m. and closed at 5 p.m. Steam varied from 79 to 95 lbs. pressure. Ashes drawn at 11-10 a.m., 1-20 and 4-15 p.m. Dampers closed from 9 a.m. till 9-53 a.m. and from 2 till 2-52 p.m. for meal hours. Gases sampled from 11-16 to 11-23 a m., 12-44 to 12-52 p.m., 3-29 to 3-41 p.m., and 3-49 till 3-56 p.m. Fire bars 3 feet long.

Average draught at front of boiler in side flues was 1·11 ins. w.g.

The ashes in this trial were all drawn out of the flue tubes, and metal dampers replaced to prevent too great an amount of air passing through the flues. The plates, however, were so twisted that they were of very little use for this purpose, and were not used in the boilers alongside.

No. 9.—The same boiler as in No. 8 trial, and the dampers in the same position.

Trial began at 7 a.m. and closed at 5 p.m. Steam varied from 75 to 95 lbs. pressure. Ashes drawn at 10-20 a.m., 12-20 noon, and 3-50 p.m. In this trial only the large clinkers were taken out, and the fine ashes left to prevent so much air passing into the flue tubes, with the result of increased efficiency in steam raising. Gases sampled from 11-56 to 12-6 noon, 12-50 to 1 p.m., and 4-40 to 4-48 p.m.

Average draught at front of boiler in side flues was 1·3 ins. w.g.

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No. 10.—This boiler was the end boiler of a range of six boilers, ive of which were working at 50 lbs. steam pressure.

Dampers area, 6 square feet, full open to main flue during trial. Main flue about 35 feet long and 16 square feet area to chimney. Between the trial boiler and the chimney there is a self-regulating damper, set to close at 50 lbs. pressure on the other boilers, which closed ten times during the trial for about two minutes, but did not stop boilers working.

The gases from furnaces went down below the boiler and then split along the sides to the main flue.

Trial began at 7 a.m. and stopped at 5-30 p.m. The engine stopped from 10-8 till 10-23 a.m. for oiling, and the dampers closed then also. Steam varied from 43 to 117 lbs. pressure. Ashes drawn at 12 noon and 5-30 p.m., sufficient fine ash being left to prevent too much air passing. Gases sampled from 11-50 to 11-59 a.m., 1-39 to 1-46 p.m., 3-20 to 3-30 p.m., and 4-32 to 4-41 p.m. Fire bars 5 feet 2 inches long.

Average draught at front of boilers in side flues was ·6 ins. w.g.

No. 11.—This was one of two boilers in one range and connected to the same chimney. There was a range of four boilers connected to the same chimney, fitted with Vicar's mechanical stokers, which during the trial emitted so much smoke that I was unable to observe the amount of smoke emitted by the boiler under test.

The furnaces were fitted with rocking bars, 5 feet 10 inches long, and patent fire doors which admit air all round side of doors to furnace, by Messrs Duncan Stewart & Co., London Road Iron Works, Glasgow. The bars were fixed during trial, and most of the air holes filled up with clay. The gases from furnaces were split along sides and went back below boiler to damper and main flue. Damper full open during trial, and 6·7 square feet of area. Flue from damper to main flue about 185 feet, and 8 square feet area, and main flue to chimney about 79 feet long and 12 square feet area.

Trial began at 8-30 a.m. and closed at 5-15 p.m., continuous.

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Steam varied from 29 to 40 lbs. Fires cleaned 10-30 a.m., 12-45 p.m., and 3 p.m. Gases sampled at 11-30 a.m., 1-15 p.m., and 2-45 p.m. Fires stirred between each charge. Flues cleaned middle of July previous, and boilers washed out every six weeks.

Average draught at front of boiler in side flues was ·2 ins. w.g.

Draught poor on account of tortuous and small flues and too small diameter of chimney for the work.

No. 12.—This boiler sits on iron stools, is quite free all round, and is covered with non-conducting composition. The gases from the furnaces pass to front of boiler through the tubes and uptake into the iron chimney.

Trial began at 7-45 a.m. and ended 5-5 p.m. Damper closed from 9 till 9-55 a.m. and 1 till 1-55 p.m., and was full open during rest of time, but no steam withdrawn for two hours. Steam varied from 47 to 66 lbs. pressure. Fires cleaned at 11 a.m. and 3-30 p.m. Gases sampled 11-37 a.m. to 12-18 p.m., 2-25 to 3-9 p.m., and 3-48 to 4-28 p.m. Trial took place on Tuesday, and tubes were swept on Saturday previous. A Cornish boiler assisted to do part of the work during the trial. Fire bars, 4 feet 11 inches long.

No. 13.—The same boiler as in trial No. 12, but doing all the steaming required for the establishment. Damper full open during the trial; closed from 8-55 a.m. till 9-55 a.m., from 12 to 12-10 on account of a belt repair, and 12-55 till 1-55 p.m.

Trial began at 7 a.m. and closed at 5-15 p.m. Fires cleaned at 10-45 a.m. and 3-45 p.m. Gases sampled from 11-46 to 12-1 noon, 2-47 till 3-26 p.m., and 4-23 till 4-48 p.m.

No. 14.—The boiler in this trial was of the same dimensions as in Nos. 12 and 13, but was built in brickwork similar to a Lancashire boiler, and was placed close to bottom of chimney. Gases from furnaces passed through tubes, then split along sides and bottom to boiler damper. Damper full open during trial, and 4 square feet area; closed from 9-15 till 9-50 a.m.

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Trial began at 8-52 a.m. and closed 5-30 p.m. Steam varied from 42 to 70 lbs. pressure. Fires cleaned 9 a.m. and 1-45 p.m., and well stirred between each charge. Gases sampled from 11-35 to 12 noon, 1-12 till 1-31 p.m., 3-10 till 3·57 p.m., 4-42 to 5-9 p.m.

During this trial a Cornish boiler, near at hand, was connected to same chimney, so that the smoke emitted was not noted. Fire bars 6 feet long.

No. 15.—Same boiler as in No. 14, working alone, damper full open all the time.

Test began at 7-7 a.m., ended at 4-53 p.m. Steam varied from 53 to 78 lbs. Fires cleaned 9 a.m. and 2 p.m., and stirred slightly between each charge, but well pokered up at 10 a.m. and 3 p.m. Gas samples drawn from 11-15 till 11-43 a.m., 1-15 till 1-41 p.m., and 3-15 till 3-51 p.m. During two hours of the trial steaming very easy.

No. 16.—This boiler was at the end of a range of similar boilers to the left, and all of them were at work during trial.

The gases after leaving furnace went up through between tubes and over division at the bridge, thence straight away to main flue, 12·5 square feet area and about 12 feet long. Damper, full open during trial, 12 square feet area.

Trial began at 7 a.m. and closed at 5-10 p.m. Continuous steaming. Steam varied from 45 to 60 lbs. pressure. Fires cleaned between 9 and 10 a.m. and 1 and 2 p.m., and stirred between each firing. Gas samples drawn from 7-50 till 8-14 a.m., 10-22 to 10-49 a.m., 11-21 till 11-49 a.m., 12-22 till 12-49 p.m., 3-8 till 3-34 p.m., and 4-14 till 4-44 p.m. Boiler cleaned on 12th March, 1893. Firebars 6 feet long and 7 feet 6 inches wide.

Average draught at furnace doors was ·31 ins. w.g.

No. 17.—Same boiler as in No. 16. Damper full open. Trial began at 7-10 a.m. and closed 3-50 p.m. Steam varied from 45 to 60 lbs. pressure. Fires cleaned between 9 and 10 a.m. and 1 and 2

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p.m. Gas samples drawn from 7-50 till 8 20 a.m., 10-33 till 11-10 a.m., 12-20 till 12-43 p.m., and 2-29 till 2-58 p.m. The ashes in all cases were drawn at the close of each trial.

Average draught at furnace doors was ·36 ins. w.g.

At the close of the trials the water was left at same height in the glass, steam pressure as near as possible the same, and fires in same condition as at the beginning; the ashes drawn from below furnaces and weighed, and where the feed water was measured into tanks for the pump or injector it was brought up to the same level as at the beginning. Coal and gas samples packed up for sending to analyst, and all the instruments packed up carefully.

If all the dimensions of boilers, flues, chimneys, and other details had not been taken before beginning trial, the following day was devoted to this work.

Diagrams.—The annexed diagrams show the variations in the steam pressures, height of water in gauge glasses, barometer, temperature of the air entering furnaces, temperature of the exit gases, and speed of the air in lineal feet per minute entering the furnace below firebars.

The letter S indicates times when gas samples were drawn.

The letter A indicates time when ashes were drawn from boilers fitted with mechanical stokers.

The letter C indicates when fires were cleaned in hand-firing trials.

The letters L.F. indicate left-hand furnace.

The letters R.F. indicate right-hand furnace.

I shall now briefly touch upon one or two points suggested by a glance at the table of results obtained, and, in the first place, draw your attention to the effect of the quantity of air supplied to the furnace as it affects the evaporative efficiency of the boiler.

In trial No. 1, the water used per lb. of fuel carbon value is only 6·93 lbs. (see line 19), and the heat utilised in doing this is only

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46·16 per cent. of the fuel, simply owing to the large excess of air supplied, which was 6·69 times the theoretical amount.

In trials Nos. 8 and 9, the better result obtained in No. 9 was obtained solely by diminishing the supply of air by leaving the fine ash in a heap at the end of the firebars, instead of clearing all the ashes out as in trial No. 8.

In No. 11, even with the disadvantage of small and tortuous flues and consequent poor draught, the efficiency rose to 60·59 per cent. with 1·53 times the theoretical quantity of air, and using 9·13 lbs. of water per lb. of fuel carbon value.

In No. 14 the boiler was being driven at a higher rate than was compatible with obtaining the best efficiency from the fuel, while in No. 15 the slower rate was more conducive to the efficiency of combustion and steam raising, and must be pretty near the best rate of working this boiler with economy.

In trials Nos. 14, 16, and 17, the boilers were driven at too high a rate for economical working. In none of the other cases were they driven above their best rate of working, while in some cases the rate could have been considerably increased with advantage.

Another point worth noting is the fact that in the exit gases the proportion of carbon dioxide, or carbonic acid, is high in the cases where the evaporation per lb. of fuel is high, and where the highest percentage of calorific value is used in heating water.

Where the fuel has approached perfection in combustion, a fairly close agreement may be noted between the actual results obtained and the practical heating power of the fuel as given in line 49 of the table; as, for instance, in Nos. 5, 6, 7, 11, and 15, where the water per lb. of fuel from feed temperature (see line 17) is given at 6·75 lbs., 6·55 lbs., 6·1 lbs., 5·97 lbs., and 6·95 lbs., as against 6·22 lbs., 6·22 lbs., 6·40 lbs., 5·84 lbs., and 6·98 lbs. practical heating power.

With regard to the best method of consuming fuel, theory agrees with practice in pointing out that the fuel should be fed continuously into the furnace at the rate of speed necessary to effect complete combustion with the minimum quantity of air, and these conditions have been most nearly met in trials Nos. 5, 6, and 7.

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I trust that no one will run away with the idea that the machine used in these trials is therefore the best, and only needs to be applied to any boiler to obtain similar results. The fact of such results having been obtained, was as much due to the skill displayed in the handling of the machine and fuel as anything else, and in the other trials, where high results have been obtained, the credit is due in the main as much to the fireman who was on duty as to any other reason.

In trial No. 1, for instance, where the apparatus was beyond the control of the fireman, he took 50 per cent. more out of the boiler of the same dimensions alongside without any extra work, fuel, or care, and without the slightest difficulty.

It may be said that these results are far better than can be obtained in every day work, and that the men, knowing their work would be compared with others, did their level best. Even if we allow this to be the case, I consider that there is not the slightest difficulty in obtaining an all round efficiency of 60 per cent. of the heating power of the fuel. I believe I am not understating it when I say, that the average efficiency does not exceed 50 per cent. of the calorific value of the fuel, thus showing a saving of 10 per cent. of the fuel, which can be effected with the emission at the most of only the faintest trace of smoke at the head of the chimney.

This can be done either by hand firing or mechanical stokers, but the men in charge must know and practise their knowledge of how to fire, and take the most out of the fuel.

In considering the amount of the fuel utilised in raising steam, it must not be forgotten that, in addition to raising steam, work has to be performed in raising the gases which leave the furnace up to the top of the chimney, in heating the cold fuel to the point of ignition, in heating the cold air supplying the furnaces with the necessary oxygen, and evaporating the moisture in the fuel. In doing all this a percentage of the fuel charged into the furnace is used up, so that if, say, 70 per cent. is utilised in raising steam, the most of the remaining 30 per cent. is not wasted, but does useful work, and the question for all steam users is so to work their boilers

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that as high a percentage as possible is utilised in raising steam, and so putting further away the time when our coal supply will cease.

With regard to proportions of grate surfaces, and flue and chimney proportions, the rules given by the late Professor Rankine will give good results if acted upon in putting down boiler installations.

I regret that time has not permitted me to go into other points suggested by a comparison of the results obtained in these trials.

Before closing, I take this opportunity of acknowledging the ready assistance given me by the owners, managers, engineers, and firemen of the various places where I carried out these trials, and without which it would have been impossible for me to have given these results now before you.

The discussion on this paper took place on 26th February, 1895.

Mr HERBERT FLETCHER, Bolton, writes:—

I am much obliged by the proof of paper and invitation to make remarks for next meeting:—

The Manchester Branch of the National Committee for Testing Smoke Preventing Appliances have made about 42 tests, one half being of hand firing and the other of machine firing—15 of the machines being cokers and 6 sprinklers.

They have supplemented these tests, which were not numerous enough to go far to settle their relative smokelessness, by observing for a whole day of 10 working hours the principal chimneys in Bolton and Oldham, noting the results as minutes of dense, medium, and faint smoke, as you have done in a few instances.

More attention has been paid to smoke in these two towns than in any others by the authorities, and they now show a better average, apart from the iron forges, than do other manufacturing towns, with the exception only perhaps of Manchester.

Between the old style of hand firing, in which no attention is paid to the prevention of smoke, and which heads the classification

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with 44 examples, and an average of 15·2 minutes per hour of all shades of smoke, expressed in terms of dense—dividing the medium by 4 and the faint by 16—and the coking stokers, of which there are 24 examples, averaging 1·9, come the sprinkling stokers, with 31 examples, and an average of 10·4 minutes.

There were 9 examples, however, of hand firing, averaging 4·3, where leaving the doors ajar for a minute or two after firing was the only means resorted to for preventing smoke.

The best of the cokers had an average of 0·4, the chimney having 3 boilers (Lancashire), 8 feet diameter, burning 80 tons in 60 hours with a chimney 56 yards × 6 feet diameter inside at top, evaporating 8·78 lbs. of water from and at 212 degrees per lb. carbon value. This was the least economy of the coker tests, the average of which was 9·61 without economiser.

In contrast with this I will quote the most smoky result of hand firing. Six boilers, four being 7½ feet diameter (Lancashire) and two 8½ feet, burning 165 tons in 60 hours, the four having a poor and the two a good draught, and emitting throughout the whole day an average of 36 minutes dense, 8¼ medium, and 8½ faint smoke, amounting to 38·79 on our system of standardising.

Roughly speaking, it seems to be all a question of draught. If it is good, without other appliances than leaving the door ajar, the smoke can be reduced to an average of 4 minutes; if it is poor, the coking stoker seems the only remedy.

Four minutes an hour—the best of these examples of doors ajar and good draught—is, however, ten times as much as the best coker example under similar circumstances of cotton mill driving, and where the fuel is small and dirty this average of four minutes will be much exceeded.

The fireman's rake seems to be the chief cause of smoke. It is scarcely used in any of the good examples; the machine that requires its use cannot compete for smokelessness, and where this is not automatic, and is dependent on the fireman, the preventive will not be applied when it is supposed attention is not being directed to the chimney.

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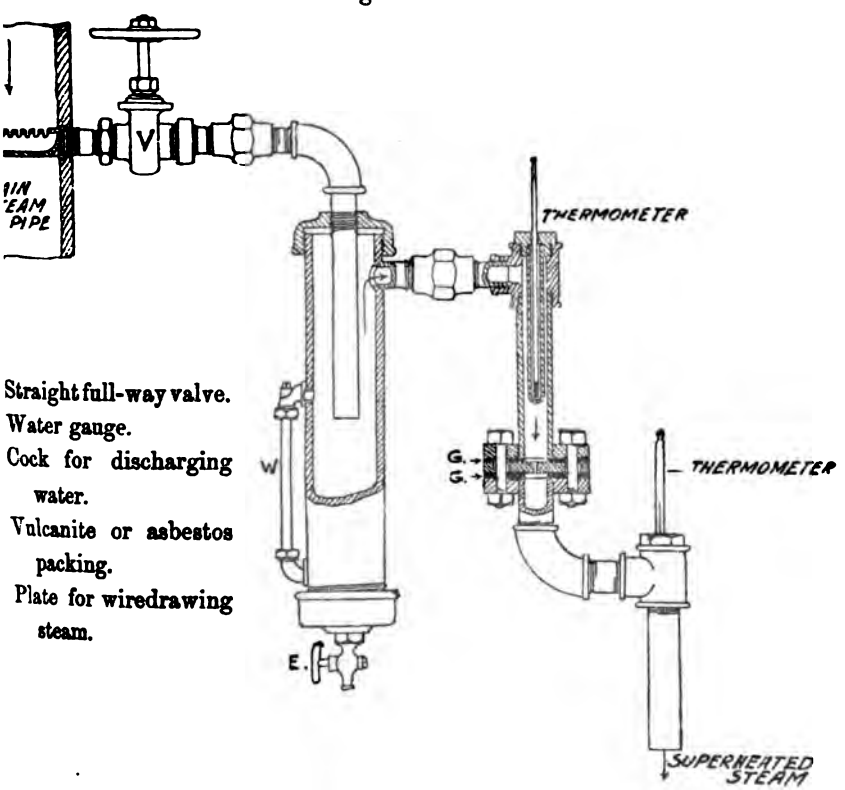
Professor WATKINSON called attention to page 102, where Mr Thomson said that owing to there being no satisfactory method of determining the amount of priming water in the steam, the test was not made in any of the cases. He thought there was one very good method of accomplishing that, and he had with him an instrument of the Barrus type, which he had recently had made, by Messrs T. S. M'Innes & Co., of Glasgow, for testing the amount of water in the steam. The test was an exceedingly simple one. A nipple was simply put into the steam pipe, as shown in Fig. 13, and a

Fig. 13.



Straight full-way valve.
Water gauge.
Cock for discharging water.
Vulcanite or asbestos packing.
Plate for wiredrawing steam.

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sample of the steam was passed continually through the instrument, and superheated by wiredrawing as it passed through the small hole in the wiredrawing plate. It was best to take the sample of steam from the steam pipe near a stop valve, through which the steam had just passed, as in passing through the valve the steam was thoroughly mixed. The only observations necessary were the temperature of the steam before and after wiredrawing, and the calculation was exceedingly simple. The total heat of the mixture of steam and priming water before wiredrawing was equal to the total heat of the superheated steam after wiredrawing, and therefore

$$S + xL = H + \cdot 48\ (t - 214^\circ),$$

where x is the dryness fraction of the steam, S the sensible heat of the mixture of steam and priming water before wiredrawing, L the latent heat of the steam before wiredrawing, H the total heat of steam after wiredrawing, t the temperature of the steam after wiredrawing, and ·48 is the specific heat of steam at constant pressure. As the pressure after wiredrawing is always slightly above that of the atmosphere, it is usual to subtract 214 from t instead of 212. When the percentage of priming water exceeded a certain amount, it was necessary to put on a separator. If the steam was at 200 lbs. absolute pressure, the separator would not be necessary, as long as the priming water did not exceed 6 per cent. If it were more than that then they must put on the separator and add the percentage of water collected to the percentage of water accounted for by the wiredrawing part of the instrument.

Professor BARR said he did not think that he could agree with Mr Thomson that "carefully conducted experiments to find the actual work done by the fuel under consumption have been conspicuous by their rarity or total absence." He supposed that Mr Thomson meant that though large numbers of experiments had been made, they had not been of such a kind that they could at once be rendered applicable to all cases. Mr Thomson went on to say—"I am not aware that any reports have hitherto appeared in the ordinary engineering journals of a sufficiently practical nature to be

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of general use to factory owners in this district." If he understood Mr Thomson correctly, he was afraid he was looking for something which could never be obtained; and, if he might be allowed to say it, he thought that engineers were too apt to look for data from experiments that would be applicable to every kind of case whatever. The difference between those experiments which Mr Thomson had brought forward and many others that had been published was principally that Mr Thomson's had been made under more ordinary working conditions than those which had generally been followed, but he thought that what they had got to lay before steam users was not what was the ordinary practice at the present moment with ordinary careless firing, but what was possible of attainment with knowledge and care. He thought that he must disagree with Mr Thomson in saying that there were no such experiments that were useful. Records had been published of a great number of very valuable experiments by Prof. Kennedy and Mr Donkin and others. On page 100 Mr Thomson referred to anemometer tests. He did not find that Mr Thomson had made use of them in determining the quantity of air entering the furnace, and he was glad if it was so, because, if the subject of priming, which he had dismissed by saying that it could not be sufficiently accurately determined, was to be passed over for that reason, he thought that any test by an anemometer of the amount of air admitted to a furnace was much more liable to inaccuracy. Professor Watkinson had spoken of the subject of priming. It would be known to many members of the Institution that Professor Unwin, at a recent meeting of the British Association, gave an admirable paper on the subject of the determination of the dryness of steam; and at the meeting of the Institution of Mechanical Engineers, held a few weeks ago in London, he gave another paper on the same subject, which gave rise to an interesting discussion. He (Professor Barr) thought that probably the kind of calorimeter that Professor Watkinson had referred to was the one that would prove most reliable; but he thought also that there was a great deal to be said with regard to the general subject, independently of the particular kind of calorimeter that was used. The

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greatest difficulty, he believed, was, not to get a good calorimeter, but to get a true sample of the steam. He had made some remarks on that subject on a former occasion,* and he had spoken on the subject at the meeting of the Institution of Mechanical Engineers referred to. He disagreed with the view expressed by Prof. Unwin that because there was a rapid eddying motion in the steam pipe, the steam and water would be thoroughly mixed. Any water that came into contact with the sides of the pipe would remain in contact with the sides, and flow along them, and therefore he believed that usually a sample taken from the body of the pipe would be drier than the bulk. It seemed to him possible to get a better sample than was usually obtained, by causing the steam to pass through nozzles in such a manner that any water flowing along the sides of the tube would be disengaged and mix with the steam. That, however, was only one part of the difficulty. There was also the difficulty of drawing off a true sample at the nozzle. The usual method that Professor Watkinson had referred to, of taking the sample through a number of holes in a pipe, was rather condemned by Professor Unwin, on account of the adhesion of water to the surface of the sampling pipe. But suppose they took a sharp-edged orifice directed against the flow, that source of error would be removed. Still there was another source of error. If the steam was flowing slowly through the nozzle, as compared with its velocity in the steam pipe, the result would no doubt be that the steam coming toward the nozzle would pass it in curved stream lines, while the heavier water particles would go straight on into the sampling tube, and thus too wet a sample would be got. If, on the other hand, the flow into the sampling nozzle was too rapid, steam would be drawn in from the surrounding parts without a corresponding amount of the heavier water particles being induced to enter, and the result would be too dry a sample. Therefore he thought that besides using the arrangement proposed, or some such

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* Volume XXXVII., page 112.

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arrangement for thoroughly mixing the water clinging to the pipe with the steam before sampling, care should be taken that weight of sample drawn per minute should bear the same ratio to the weight of steam passing the nozzle per minute as the area of the nozzle bore to the remaining portion of the cross sectional area of the steam pipe—in other words, that the velocity of flow through the orifice, and the velocity of flow past the orifice, were the same, so that every particle of water carried along by the steam might be perfectly free to go straight on, and every particle of steam perfectly free to go straight on. The points were then (*a*) the mixing of the steam with the water that ran along the surface of the pipe, (*b*) the taking of the sample out by a sharp-edged orifice, and (*c*) the securing that the velocity of flow through that orifice should be exactly the same as the velocity through the remainder of the pipe. In the first formula given at the foot of page 103 for the calculation of the calorific value of fuel, the weight of hydrogen present in the coal was lessened by an amount equal to the weight of the oxygen divided by 8. That was done upon the assumption that there was no free oxygen in the sample of coal, but that all the oxygen in the sample was already combined with hydrogen to form water. He understood, not only from his own ideas on the subject, but from conversations with chemists, that that was entirely a wrong conception, and that the deduction should not be made. There was another consideration, however, that greatly complicated the question. All the hydrogen was not in the form of free hydrogen, and all the carbon was not in the form of free carbon, but some portions of the two were combined together, and the compounds had to be split up before the carbon could be burned to carbon dioxide, and the hydrogen to water; and therefore the carbon and the hydrogen should each be represented by at least two values—the amount of combined carbon and the amount of free carbon, and the amount of combined hydrogen and free hydrogen. On the other hand, the carbon in the gaseous compounds being already in the gaseous state, did not require to have heat (latent heat) expended in its gasification. The latter condition was the more influential, and therefore the

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present, in the form of hydrocarbons, had a greater available heating value than the solid carbon.*

Mr JOHN BARR (Kilmarnock) said that Mr Thomson did not state what standard he used in estimating the theoretical quantity of air required to burn the fuel, and then he did not state in estimating the amount of feed water whether he made any allowance for expansion of the feed water when at a higher temperature. The higher the temperature of water the greater the bulk, and he did not say whether he made any allowance for that.

Mr LINDSAY BURNET writes—I regret that ill health prevents me from being present at the discussion on such a useful communication as Mr George Thomson's; but, since I have keenly studied the boiler question, or rather the economics of steam generation, for some years back, I should like to make a few observations. Mr Thomson designates his communication as "Results of Evaporative Tests on Land Boilers," but it is more than that, inasmuch as it includes observations on the combustion of the fuel, a most important item of the boiler question; indeed, I would go so far as to say the most important item, at least as regards the engineering efficiency as opposed to the all important matter of commercial efficiency, with which the steam user alone concerns himself. I believe that, taking the accepted types of boilers, the small differences in their values as regards heating surface, or transmission of heat, would surprise those engineers who have not had need or opportunity of closely eaxmining the question, and that the greatest differences are to be accounted for by the differences in the furnace and in the furnace gas passages or flues, and in the skill of the attendant, and thus the choice of any of the well known and tried types of boilers, so far as efficiency of transmission of heat is

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* M. Cornut gives the formula—

Heating value = $8{,}080\,c' + 11{,}214\,c'' + 34{,}462\,H$,

or in Fahrenheit units say = $14{,}500\,c' + 20{,}200\,c'' + 62{,}000\,H$,

where c' is the fixed carbon, c'' the volatile carbon, and H the hydrogen.—See F. J. Rowan, "Journal of the Society of Chemical Industries, 1888," page 196.

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concerned, becomes merely a question of the location of the plant, the space available, cheapness of carriage, erection, and upkeep. But when the total question comes to be settled involving the other, and as I maintain most important, item of furnaces, flues, etc., the matter is much more involved, and more especially so in our district, where our available fuel varies so much in quality, and the heat power of which so largely exists as volatile matter. The other day, in a lecture, my friend, Dr Kennedy, of London, spoke of our fuel as "rubbish," but if you refer to columns 5, 6, and 7 of Mr Thomson's table you will see what wide-awake steam users can do with "rubbish." This table of results is very interesting. In column 1 we have hand firing with one of the innumerable hollow bridge dodges. Now, if the same quantity of fuel be put on at each firing it would be practically possible to find out how much air should be passing up through the said hollow bridge; but the average fireman has not the intelligence, even if he has opportunity, either to fire equally or work the shutter of the hollow bridge, and in this case evidently the door has been constantly open, and has thus permitted the gases to be drenched, so to speak, with air. Very often these patents get out of order and burnt, and when the fireman is changed his successor goes ahead without knowing that there is anything amiss. The same fault occurs in the trials in column 8, through inattention of the fireman; this machine stoker having no back bridge, and being dependent on an accumulation of ashes and glowing fuel to prevent undue air leakage to the gases. This drenching of the gases by an overplus of air is a very common source of loss, and especially so when uneducated attempts are made to secure smokeless combustion, and it is by no means the uncommon experience of steam users to find that after the patent smoke consuming man (who has fitted his appliance and run it carefully himself) has departed, and his influence gone, more fuel is being used than before he appeared; thus the scrap heap grows, and the steam user's belief in all appliances, and even in the possibility of smokelessness, is shaken, if not for ever shattered. Columns 12 and 13 show a boiler struggling with too small a chimney, while Nos. 14

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and 13 show a fire grate too large for the fuel required. Many engineers speak of so many lbs. of coal per square foot of grate as being the proper amount to burn, but it surely all depends on the quality of the fuel, size of that fuel, type of grate, and the available draught, and thus since few steam users are in the happy position of having their plant truly proportioned, there is always room for the patent fire-bar man, the mechanical stoker man, the steam-jet draught man, and others of that genus, and some steam users being careless, and having their plants in a truly sad condition, are considerably benefitted by a comparatively poor device. I am glad to see that Mr Thomson acknowledges the necessity of the attendant on mechanical stokers being a superior man, and I believe that this point regulates to a great extent the expediency of adopting any of the present machines in a small plant of boilers, just because if the saving of wages through the employment of fewer men only covers the considerable cost of upkeep of the mechanical stoker, one would rather employ the intelligent high paid hand stoker. When will the boiler fireman be recognised and paid as a tradesman? There will be less smoke when he is so recognised. Those men deal with the black diamonds, which in the life of a single boiler, say 25 years, amount in value (taking the consumpt at 23 tons per week) to £10,000; who then is going to refuse even 5 per cent. on that? and some steam users in our district have 30 to 40 boilers.*

Mr A. S. BIGGART thought that many of the members of this Institution had waited with expectancy for Mr Thomson's report, and they were now glad to see it. They must not forget, however, that the primary object of these experiments was to determine for the steam user some effectual but simple means of consuming smoke. They knew from Mr Thomson early in his experiments that something in the way of a mechanical stoker was probably the best. His firm had put in a mechanical stoker, and, after an experience of two years, they could say that it had worked with most satisfactory

* Mr Lindsay Burnet has since passed away at the early age of 39 years. Mr Burnet was elected a Member of Council in April, 1894.

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results in every respect. Formerly they had had repeated visits from the police, but all they could do even with the most careful firemen to reduce the smoke did little more than keep them out of the Police Court. After the mechanical stoker was put in, black smoke was a thing unknown from that particular stalk. It had been in use for two years, and, with the exception of one little cam that was broken shortly after it was started, there had not been a single penny spent on that mechanical stoker during that time. Mr Thomson had said, and said rightly, that if careful hand firing was adopted they might consume the smoke by this means, but the difficulty lay in getting careful hand firers. The result was that by a very simple means they had consumed their smoke, although it was only right to say that while they were led to believe there would be a good deal of economy in the consuming of it, that had not turned out to be the case so far as any experiments which had been carried out had shown. While the water evaporated per pound of coal was greater than that by hand firing, still they found that the extra steam raised was all used up in keeping the fire bars clear. That had been the secret of the little trouble they had had with this mechanical stoker. He was sure they all desired (for the sake of their own health and comfort and that of their fellow-citizens) and would try to influence those who might be termed smoke manufacturers to adopt some of the mechanical appliances suggested by Mr Thomson to remedy this crying evil.

Mr THOMSON, in replying, said that with reference to priming he had all along had a great objection to call the small amount of moisture carried over with the steam "priming water," as that was not the usual meaning attached to the word by engineers in general, which was when the water was carried over in such quantity as to interfere with the safety and proper working of the engines supplied by the boilers. In the distillation of water it was impossible to get the first distillate pure, no matter how much care was taken, as a small proportion of the water was invariably carried over mechanically, and he thought it would be better to confine the word "priming" to its usual signification, and not use it to include every

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trace of moisture in the steam. Referring to Professor Watkinson's remarks on the determination of the amount of moisture in the steam, and the instrument which he exhibited and explained, and also to the remarks of Professor Barr on the same subject, he considered that to give the boiler a fair chance the instrument should be placed as close to the stop valve as possible, but his experience was that as a general rule the space over the boilers was not very suitable for placing such an instrument and getting trustworthy observations from it, and the light was generally bad. He believed that with an instrument of the class shown concordant results could be obtained more readily than from most others that had been tried, but he considered that the difficulty lay not so much in getting a reliable instrument as in getting a fair average sample of the steam as it issued from the boiler. He did not think that the usual way, as stated by Professor Watkinson, was capable of giving an accurate sample of the steam, neither did he believe that the method proposed by Professor Barr and illustrated by him would give any better result than the previous method, as it failed to comply with the condition laid down, as it was well enough known that the steam in the centre of the pipe travelled faster than it did at the sides, and the use of the mixing apparatus in the pipe before the steam reached the sampling tube would result in getting too wet a sample. He had read Professor Unwin's paper on this subject, and he agreed with his conclusions that as yet no exact method of determining the amount of moisture was in existence. With regard to Professor Barr's remarks on his (Mr Thomson's) statement regarding boiler experiments, and instancing those of Professor Kennedy, Mr Donkin, and others, he was quite aware of these very valuable and interesting experiments, and while they were of very great use and value to those who could use Welsh coal of the best class, he still considered that they were practically of no use in this district, and in other districts where the fuel was of a bituminous nature, and containing such a large proportion of its heating value in the volatile portions, rendering necessary the use of different methods of firing if the best

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was to be taken out of the fuel, and the emission of black smoke was to be avoided. He did not consider that the results given in the table, in a number of cases, could have been obtained from the practice of ordinary careless firing (see Nos. 2, 5, 6, 7, 11, and 15), and even these results, good as they were, could be surpassed with knowledge and care; and he considered the results compared favourably with those obtained by other experimenters in this field. In answer to Mr John Barr's questions, he stated that the quantity of air used was obtained by calculation from the analysis of the exit gases, and the amount required by theory from the analysis of the coal used in the trial. The weight of the water given, as used in the trial, was obtained from the measured volume and temperatures taken regularly, as described in pp. 100 and 101, and reduced to the same standard. With regard to the anemometer tests, no use had been made of them further than to show graphically in the diagrams the state of the fire, and how the air had taken advantage of any bare spaces on the furnace bars, and in the case of the machine firing trials, of passing at the ends of the bars through the accumulated heap of ashes at that point. The makers of mechanical stokers, however, made great use of the anemometer in estimating the draught available at the boiler furnaces, and so it was given in order that those who wished might see the relation between the readings of the anemometer and the water gauge in the matter of draught. Professor Barr, in his remarks on the calorific value and chemical composition of the fuel, was perfectly correct, and he thought he could not do better than quote the following conclusion from Mr William Kent's paper on the heating power of coal, as given in "Mineral Industry," Vol. I., page 105. Referring to a diagram given in the paper, giving the results of various experimenters on this subject, he states :—

"1st.—Mahler's results group themselves very closely around the average curve of the diagram, indicating therefore that there is a law of relation between the composition of the coal, as determined by proximate analysis, and the heating value, as well as between the elementary composition and the heating value. Knowing, therefore,

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the percentage of fixed carbon in the dry coal free from ash, we may, in the case of all coals containing over 58 per cent. of fixed carbon, predict their heating value, within a limit of error, of about 3 per cent.

"2nd.—This close grouping of the several tests about an average curve indicates great uniformity of action of the calorimetric apparatus, and a high probability of its accuracy, unless there is a constant or a uniformly proportional error, which is not probable to any important extent.

"3rd. — Mahler's results are regularly lower than those of Scheurer-Kestner for coals of similar composition, and more closely approximate the theoretical heating power, as determined by Dulong's formula; indicating that Scheurer-Kestner's apparatus and results were not as accurate as those of Mahler, and that Scheurer-Kestner's observation that the heating power of coals is generally greater than that determined from their composition is not true to the extent believed by Scheurer-Kestner, especially in the case of coals containing over 70 per cent. of fixed carbon.

"4th.—From the average curve through Mahler's results the following table may be constructed :—

Approximate Heating Value of Coals.

Percentage of fixed carbon in coal, dry and free from ash.	Heating value.		Percentage of fixed carbon in coal, dry and free from ash.	Heating value.	
	Calories.	British thermal units.		Calories.	British thermal units.
97	8200	14,760	63	8400	15,120
94	8400	15,120	60	8100	14,580
90	8600	15,480	57	7800	14,040
87	8700	15,660	54	7400	13,320
80	8800	15,840	51	7000	12,600
72	8700	15,660	50	6800	12,240
68	8600	15,480			

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Below 50 per cent. of fixed carbon the law apparently does not hold, as is shown by the tests of some of the lignites, which depart considerably from the average curve. The cannel coal and the turf from Bohemia, tested by Mahler, lie far above the average curve.

In the case of the cannel coal this may be accounted for by the relatively high percentage of hydrogen and low percentage of oxygen; but it is difficult to account for the high value shown by the turf.

"5th.—The comparison of the industrial or steaming power by Johnson's and Grüner's tests with the heating value as determined by a calorimeter strongly emphasises the fact that in the burning of highly bituminous coals under ordinary steam boilers a greater percentage of heat is lost than in the burning of anthracite and semi-bituminous coals.

"There is but little difference in the calorimetric heating power of coals containing, respectively, 70 per cent. and 85 per cent. of fixed carbon; but in industrial practice the latter give from 15 per cent. to 20 per cent. higher results. This is simply due to the great difficulty in ordinary boiler furnaces of burning the excess of volatile combustible matter, which passes out of the chimney in smoke and unburned gases."

These remarks seemed to meet Professor Barr's, and to show that the use of Dulong's formula, in stating the theoretical heating power of fuels from their chemical composition, was the most accurate that was presently known; while Mahler's apparatus seemed to be the most accurate for determining the heating power of fuels experimentally. The bars in trials Nos. 5, 6, 7 were hollow, with a horizontal division lengthwise, and steam was admitted at the open end of the upper part of the bar, and travelled to the other end, returning by the under part of the bar, and escaping by the side near to the furnace mouth. The estimated amount of steam used in these trials was 1½ per cent. of the total evaporation, and was calculated from the steam pressure, and the area and number of issuing jets. In trial No. 3, the amount of steam used was estimated

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similarly at 11 per cent. In No. 4, the amount of steam used over the fire was ·79 per cent., and below the bars at 7·73 per cent., or a total of, practically, 9½ per cent. of the water evaporated. In trials 8, 9 and 10 no steam was used for assisting the draught, or keeping the bars cool. Mr Biggart was correct in saying that the primary object of these trials was to determine for the steam user if the emission of smoke could be abated, or prevented, by simple and effectual means, and he considered that so far as concerned the class of boilers tested, that object had been attained, but there remained several classes of boilers in common use which were good smoke producers as usually handled, which could not be so easily disposed of, and it would be of benefit if similar trials were conducted upon these classes of boilers. Since reading this paper, he had had an opportunity of seeing several of the factories in Bolton, and their furnace arrangements, and he could testify that the results obtained by, or through, the action of the authorities, had changed the character of the chimneys entirely. When he last visited Bolton, some eight or nine years ago, the chimneys were good at producing smoke of good density. Now, the majority of the chimneys were as free from smoke as those at the Regent Works, Partick; Messrs Coats & Co., Paisley; or Messrs Crum & Co., Thornliebank, which were well known as practically smokeless. The abstracted results of the trials carried out in Manchester, Bolton, and Oldham, for the National Committee for Testing Smoke Preventing Appliances, as given in the communication received from Mr Herbert Fletcher, Bolton, are very interesting, and show conclusively that a very different state of affairs, in regard to the smoke nuisance, can be brought about without inflicting any hardships on the steam user. The coal used in Bolton and neighbourhood is of better quality, on the average, than what is usually the case here. The results of these tests are being prepared for publication shortly, and they will be full of interest. He was indebted to Mr Fletcher, the hon. secretary for the Manchester district, for the privilege of seeing the means that had been adopted so successfully for dealing with the smoke nuisance. He was much obliged to members of the Institution for the kind way

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in which they had received his rather dry paper. For information regarding the causes and means of abating smoke, he must refer the members to a paper on "Smoke Abatement," read by him before the Philosophical Society, on 6th February, 1895, in which he had gone fully into the subject.

On the motion of the Chairman, a hearty vote of thanks was awarded to Mr Thomson for his paper.

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On "Water Tube Boilers."

By Professor W. H. WATKINSON.

(SEE PLATES IX., X., AND XI.)

Received and Read 22nd January, 1895.

WATER tube boilers are, for many reasons, attracting a very large amount of attention at the present time, especially in connection with their application for marine purposes and for electric light stations. This being the case, and the author having spent a considerable amount of time during the last few years in investigating and experimenting with boilers of this type, he ventured to offer a paper on the subject to the Institution, in the hope that, although the paper might not contain anything new, it would at any rate do good by inducing a full discussion on this most important branch of engineering.

The two chief reasons for the present great reaction in favour of water tube boilers appear to be the greater ease and safety with which high pressures can be carried in boilers of this type than in boilers of the tank type, and the considerable reduction which may be made in the weight of the boiler as well as in the weight of water in the boiler.

In the past every notable increase of steam pressure, under proper conditions, has led to a considerable decrease in the water and coal consumed per I.H.P. hour. With increase in pressure from 80 lbs. to about 160 lbs., the consumption of coal has been decreased by about 25 per cent. per I.H.P. hour. The theoretical saving, as deduced from the increased range of temperatures, amounts in this case to about 27 per cent. Assuming that the actual gain continues

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to practically agree with the theoretical gain, it may be easily shown that by increasing the pressure to 500 lbs. the efficiency would be still further increased by 38 per cent. and the consumption of coal reduced to a little less than 1 lb. per I.H.P. hour. With multi-cylinder engines there should be no very great difficulty in working with this high pressure, seeing that in the case of locomotives, pressures of 160 lbs. and upwards are advantageously used in one cylinder, and that in the case of gas engines pressures of over 300 lbs. are used, the whole of the expansion being effected in one cylinder. In the latter case it should also be remembered that the cylinder is filled with a white hot flame during each working stroke, and as there is no special difficulty in connection with the lubrication, owing to the adoption of dense mineral oil as the lubricant, there surely should be none in connection with steam at the comparatively low temperature corresponding to the pressure of 500 lbs. per square inch, viz., 467·4 degrees F.

Another way in which the adoption of water tube boilers may lead to greatly increased economy is by enabling steam to be generated at very much higher pressures than may be possible or convenient of employment directly in the engine cylinder, and arranging that the steam shall be wiredrawn from the high boiler pressure to that suitable for use in the engine. By this means the steam will be safely and efficiently superheated, and the losses from liquefaction of steam in the cylinders may be then greatly diminished, or altogether obviated. For example, it only requires about 5 per cent. more heat to generate 1 lb. of steam at 1000 lbs. pressure than is necessary to generate 1 lb. of steam at 200 lbs. pressure, the feed water being at 200 degrees F. If this steam, at 1000 lbs. pressure, be then wiredrawn to 200 lbs. pressure, it will, assuming the steam to be initially dry, be superheated 105 degrees F., and if the steam initially contains 3 per cent. of priming water, it will still be superheated 49 degrees F. by the above amount of wiredrawing.

Experiments recently made in France and in Germany, and in this country by Professor Kennedy and Mr Bryan Donkin, show that a considerable increase in efficiency may be obtained by super-

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heating. Some time ago Professor Kennedy tested a simple expansive engine in which steam pressures of from 9½ to 15 atmospheres were used, the steam being superheated by more than 200 degrees F., its temperature being then at 600 degrees F. No difficulty whatever was found in connection with the lubrication even at this high temperature. He also reports having examined an engine which had been at work under these conditions, every day, during a year and a half. The valve and piston were found to be in splendid condition, as neither of them passed any steam even at a pressure up to 13 atmospheres. He found that the inside of the cylinders had a smooth, glassy, and quite greasy surface. "Its condition, in fact, could not have been better under any circumstances." Mr Bryan Donkin's experiments showed an increase of efficiency, due to superheating, by only 50 degrees F. of from 15 per cent. to 27 per cent. according to the cut-off.

For pressures of 150 lbs. or 200 lbs., a superheater of the ordinary type, with steam on one side and furnace gases on the other side of the heating surface, would be most dangerous, but superheating by wiredrawing, as indicated above, would be perfectly safe. This method of superheating also gets rid of one of the greatest difficulties which has been encountered in connection with superheating in the ordinary way—viz., the regulation of the amount by which the steam is superheated. In the case of electric light stations, for example, the steam supplied by the boilers would be drier when working at light loads, and therefore the superheating due to wiredrawing would be greater, which is precisely the condition necessary for maximum economy with engines fitted with automatic variable expansion gear.

The adoption of boilers of the water tube type also renders it possible to generate steam from water which has been highly superheated under great pressure by mere reduction of pressure. For example, if water is raised to the temperature corresponding to that of steam at 1000 lbs. pressure, and its pressure be then reduced to 200 lbs. pressure, one-fifth of a pound of steam at this pressure will be generated from each pound of water thus treated. The possible

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advantages of this method, in which nothing but continuous water is in contact with the heating surfaces, are rendered obvious by the following facts. When boilers are greatly forced, a very considerable proportion of the heating surface is covered with steam bubbles instead of with continuous water; and unless the circulation is sufficiently rapid the heating surfaces become liable to serious overheating; and if the boilers are forced beyond a certain limit the heating surfaces may be burned out. The author found by experiment that if water be caused to flow continuously through a tube it was impossible to injure the tube by the fiercest oxy-gas flame which he could command; whereas when steam only passed through the tube, the tube was melted in two in a few seconds. In this connection Mr Thornycroft says:—"To obtain the highest evaporative duty from a given tube surface it is necessary that the contents of the tubes should consist of, as far as possible, water only."

If the above method of heating water under high pressure be continued until the "critical condition" is just passed, instead of only a proportion of the water being converted into steam when the pressure is reduced, the whole of it will be converted into steam, which will superheat as it expands. This critical condition is reached with water when the temperature is approximately 698 degrees F. and the pressure a little below 3000 lbs. per square inch (195·5 atmospheres). This pressure, although great, can be more safely carried in boilers of the water tube type than pressures of 150 lbs. in boilers of the tank type.

Circulation.—This is a branch of the subject which has been very much discussed, but about which very various opinions prevail. Some even go so far as to say that rapid circulation is not necessary, but only harmful on account of its being the main cause of priming. In the case of most types of water tube boilers, however, rapid circulation is absolutely necessary, as by means of it the temperature of the boiler is kept approximately the same in every part, and if this were not the case, leakage at the joints

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would inevitably result. Other advantages of rapid circulation throughout the tubes exposed to the furnace gases are—the prevention, more or less absolute, of deposit of salts and grease in the tubes. In some cases, with tubes of larger diameter, in which a large amount of local circulation must have taken place, it has been found that the tubes were burned out in consequence of the deposit of grease within them; no such burning takes place when the tubes are of smaller diameter and the circulation is less local and more vigorous. Rapid circulation also causes the films of air to be swept from the heating surface and carried up with the steam into the upper drum. When the air is not thus got rid of it causes rapid oxidation of the interior of the tubes. The causes of circulation are:—1st. Difference in density of the water due to difference in temperature when the fires are first lighted. This circulation is very sluggish. 2nd. When the water is all at the same temperature and steam is being generated, but not with sufficient rapidity to cause a break in the continuity of the water, a comparatively sluggish circulation is set up by the entraining action of the bubbles of steam rising through the water. 3rd. When steam is generated with such rapidity that in some part of the circuit there is foam only present, a very rapid circulation takes place, due to the difference in density between this foam and the continuous water in the down-comers, internal or external. These conditions are illustrated in the following diagrams. It is sometimes maintained that as the average density of the substance in the tube, B (Fig. 1), is less than that of the substance in tube, A, a circulation must take place in virtue of this. This is quite incorrect, as the pressure at the bottom of tube, B, must be equal to that at the bottom of tube, A, so long as the continuity of the water is not broken in either of them. The absurdity of this theory of circulation is at once seen if we imagine a small cup inverted over each bubble of steam, as indicated at C, in the sketch. By others it is assumed that the circulation, especially in those boilers in which the tubes are not much greater than 1 inch diameter, is of the type shown in Fig. 2. In this case, the

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Fig. 1. Fig. 2.

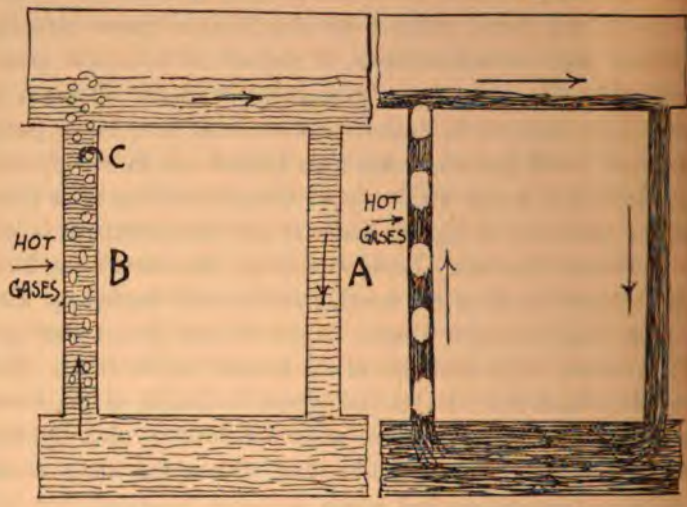
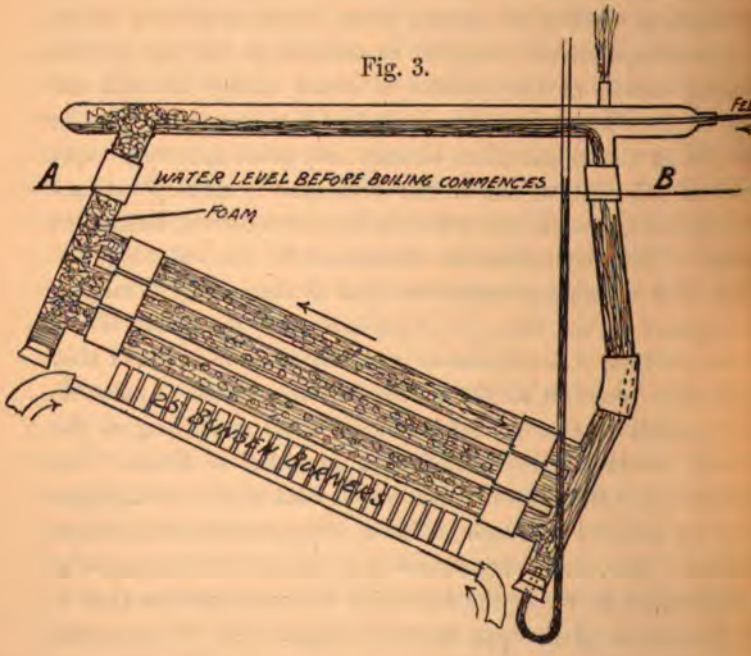


Fig. 3.



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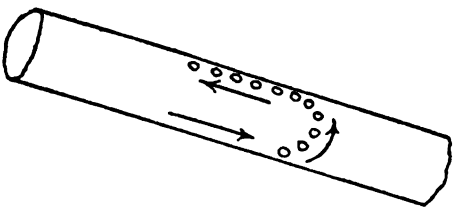
water and steam are supposed to follow each other alternately in plugs as indicated. The author has spent a considerable amount of time in experimenting with boilers built up of glass tubes about 2 feet in length, and varying in diameter from about ½ an inch up to 1½ inches, with various rates of evaporation up to 9 lbs. per sq. ft., but only when the diameter of the tubes was reduced to ½ an inch, and the tubes were nearly vertical, was he able to obtain the conditions shown in Fig. 2. In all cases, most of the circulation seems to be due to the upper parts of the tubes or the front headers, where these are used, or both, being filled with foam to the complete exclusion of continuous water. This is illustrated in sketch, Fig. 3. The line, A B, shows the water level before starting, but as soon as rapid boiling has commenced, the upper ends of the tubes and the upper headers are filled with foam, and there is a continuous flow of water along the upper drum.

With tubes of 1¼″ diam. and upwards, local circulation becomes very appreciable, especially in the upper of the three tubes shown. In this tube, while there is a continuous upward stream of steam bubbles, there is also a continuous downward stream of water. The direction of flow of the water in the middle tube, under some conditions, becomes alternating. The path of each bubble at any instant is, of course, in the direction of the resultant of all the forces acting on it at the instant. On this account the path may, when the tubes exceed a certain diameter, determined by the rate at which steam is being generated, be curved as indicated in Fig. 4.

Fig. 4.



The size of the steam bubbles formed varies greatly with the rate at which steam is being generated. When the rate is great the

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bubbles are very much smaller than when the rate is very small. The size of the bubbles also depends, of course, on the pressure under which the steam is generated.

So far as the action inside the tubes is concerned, the angle of inclination of the tubes seems to be of little moment so long as the inclination is not less than about 15 degrees and not greater than about 70 degrees, when the diameter of the tubes is about 1 inch, and it is probable that the best inclination, in any given case, depends on the diameter of the tubes. When the tubes were horizontal the water was almost entirely driven out of the lower ones, and when they were vertical the action was intermittent. So far as the utilisation of the radiant heat from the solid fuel on the grate is concerned, the boilers with tubes only slightly inclined to the horizontal have the advantage.

It is often assumed that boilers with headers will not stand as much forcing as those in which each tube discharges directly into the upper drum. In practice it is found that there is no difference in this respect.

In designing boilers of this type, especial care should be taken that none of the tubes act as condensers for the vapours in the products of combustion, as if they do, the sulphurous acid thus deposited on the tubes may soon ruin the boiler. Care should also be taken to prevent deposits of ash on the tubes.

Boilers which are more or less triangular in form must occupy a greater space for a given power than those which are more or less rectangular in form, other things being equal. This is obviously a matter of considerable importance in the case of marine boilers.

The main advantages which may be derived from the use of water tube boilers are due, firstly, to the comparatively small mass of water in them and the consequent small loss due to steam raising, and, secondly, to the much higher average efficiency under greatly varying loads. This latter point is very well illustrated by the following abstract from the tests of a Thornycroft boiler, made by Professor Kennedy :—

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H.P.		Efficiency of boiler.
89·1	-	86·8 per cent.
282·1	-	81·4 ,,
449·2	-	78·2 ,,
774·7	-	66·6 ,,

From these results it is evident that, for electric light stations, the cheapest method of storing energy is in the form of coal if proper arrangements are made for greatly varying the rate at which it can be utilised for the generation of the current required.

DESCRIPTION OF PLATES.

Fig 1, Plate IX., shows the latest type of the well known Babcock & Wilcox water tube boiler for land purposes, specially arranged for burning bituminous coal. By adopting a second combustion chamber, as shown, much more perfect combustion is obtained, and practically no smoke is sent up the chimney.

Fig 2, Plate IX., shows one of the boilers by the same makers as fitted in the steamship "Nero" of the Wilson Line. The adoption of these boilers has in this case resulted in a reduction of weight by 25 per cent., although the weight of the water contained in the boilers is about 5 tons. In this boiler there are two circuits through which the water may circulate. The principal one consists of the drum, D, the "headers," A and B, and their connecting tubes, C; the second one consists of the drum, D, the vertical tubes, E, which are placed on both sides and on the front of the furnace, and of the rectangular chambers, F, into which these vertical tubes are expanded. The circulation in these vertical tubes is downwards through those towards the rear, and upwards through the others, which are in the hotter part of the furnace. At the base of the chimney is a feed water heater, H, and the feed water is sent into the bottom of this and passes out at the top into the drum, D. All the joints in this boiler are of the expanded type. The engineer's report of the working of these boilers on the S.S. "Nero" is given in the Appendix.

The boilers recently supplied by this firm to the Glasgow Electric

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Light Station are in some respects similar to the above, but instead of one hand hole at each end of the boiler serving for four tubes, as in the above case, each tube has its own independent hand hole.

Fig. 3, Plate IX., shows the latest type of the Lagrafel D'Allest boiler. The water circulation in this is similar to that through the inclined tubes of the Babcock boiler; but the circulation of the gases is as indicated by the arrows. The gases, instead of passing vertically upwards, first flow into the large combustion chamber, C, which is common to the two boilers, and by this means more perfect combustion is obtained. In the older form of this boiler the gases passed vertically upwards amongst the tubes, and the evaporation was only 7¼ lbs. of water from and at 212 degrees F. per lb. of coal. The introduction of the large combustion chamber is said to have raised the evaporation to 10¾ lbs. of water from and at 212 degrees F. per lb. of coal. The flat surfaces of the water legs, A and B, into which the inclined tubes are expanded, are strengthened by screwed stays as shown. The holes opposite the tube ends are closed by internal doors, held in position by a bolt and external cross-bar, and the joint is made by means of an asbestos washer and copper wire. The tubes employed in this type of boiler are 2¾ inches outside diameter, the pitch being about 4 inches.

In ordinary working a small quantity of lime is continuously mixed with the feed water, at the rate of 4 lbs. per 1000 I.H.P. per 24 hours, to assist in precipitating the salts in the water. Most of the deposit takes place at the bottom of the back water chamber.

The "Belleville" boiler, Fig. 4, Plate X., consists of a series of "elements" placed side by side over the furnace. Each "element" consists of a number of tubes connected in series so as to form a flattened spiral. The tubes constituting an "element" are joined together by means of boxes of malleable cast-iron, into which the tubes are screwed. The front junction boxes are provided with hand holes through which the tubes may be cleaned. The bottom of each "element" is in communication with the feed collecting tube shown, and the top of each "element" is connected directly to the steam drum, which is constructed so as to act as a centrifugal

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separator (Fig. 4 A, Plate X.). The water level is, as shown, below the upper tubes of the "elements;" but, as a considerable amount of water is carried up with the foam into the steam drum, there is a continuous flow of water along the bottom of the drum and down the vertical pipes shown at the end of the boiler into the separating chamber.

The feed water is admitted in the form of spray into the steam drum at the end remote from the vertical "down-comer." A small quantity of lime water is added continuously to the feed water to assist in the precipitation of any salts which may be in solution in the feed water. The feed water, in flowing with the circulating water along the whole length of the steam drum is, before it reaches the separating chamber, raised to the temperature at which the salts become insoluble, and these are, therefore, owing to the comparative stillness of the water in the separating chamber, precipitated there, carrying with them any grease which may be in suspension in the liquid. The water thus purified flows from the separating chamber into the feed collecting tube, from which it passes upwards through the elements. An important adjunct to this boiler is an automatic feed regulator, which is said to give very good results.

The tubes in this boiler are usually 5 inches in diameter for merchant ships, and 3 inches in diameter for war ships.

Fig. 5, Plate X., illustrates one of a pair of water tube boilers constructed by Messrs. Fleming & Ferguson for the Canadian cruiser "Aberdeen." In these the upper drum is 6 feet in diameter, and the two lower ones 3 feet in diameter. The tubes are expanded into the drums and afterwards beaded over. Their diameter is $2\frac{1}{2}$ inches, except at the upper end, where it is $2\frac{9}{16}$ inches diameter. They are all arranged so that any one tube can be cut out, withdrawn into the upper drum, and replaced without disturbing the other tubes. The chief engineer's report on the working of these boilers is given in the appendix.

Yarrow's boiler is shown in Fig. 6, Plate X. In this figure, large external "down-comers" are shown, but these are not now fitted to

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boilers of this type, as the outer tubes, which are exposed to the gases at a lower temperature, have been found sufficient to supply all the water that is necessary for the upward currents through the inner tubes. All the tube joints are of the expanded type. The water level is at about the middle of the upper drum. The following table gives particulars of the boilers of this type used on the torpedo boat destroyer "Hornet":—

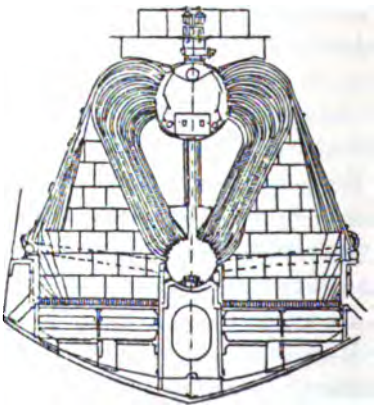
Yarrow Boilers of torpedo boat destroyer "Hornet," 8 in number.

Details of one of these:—

Tube heating surface, - -	1027 square feet.
Grate surface, - - -	20·6 "
Length of fire bars, - - -	6½ feet.
Steam raised in about 20 minutes from lighting of fires.	
Steam drum, - - -	7½ feet long.
Tubes of copper, - - -	1 inch diameter.
Evaporation—12,500 lbs. of water per hour each boiler.	
Weight of each boiler, including water and fittings, 9½ tons.	

Another type of boiler, also patented by Mr Yarrow, is shown in Fig. 7, Plate XI.

One form, the "Speedy" type of the Thornycroft water tube boiler, is shown in sectional elevation in Fig. 8, Plate XI.; and another form, the "Daring" type, is shown in annexed Fig. In this



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boiler, the discharge into the upper drum takes place above the water level, baffle plates being used to assist in the separation of the steam and water. According to Mr Thornycroft, the weight of the water thus carried over in a given time is 105 times that of the feed water, whereas when the discharge took place below the water level this ratio was only 50 to 1. In boilers of the "Speedy" type the water flows from the upper drum to the two lower drums by the external down-comers shown; and in the boilers of the "Daring" type the water flows down the central tubes to the lower drum and to the side distributing pipes which are in connection with it. From the central lower drum and the two side pipes the flow is upwards through the tubes shown respectively connected with these.

Thornycroft's experiments show that when the tubes are drowned the proportion of steam to water *in the tubes* is greater than when not drowned. With water entirely free from oil it is possible to force this boiler to give 20 lbs. of steam per square foot of heating surface without overheating the tubes, but the introduction of a small quantity of grease caused the destruction of the tubes at this rate. When the tubes are not more than 1 inch diameter the circulation is so vigorous as to actually polish the insides of the tubes. A Thornycroft boiler after being three years in service at sea, was found to have its tubes quite free from incrustation.

A boiler of the type shown in Fig. 8, Plate XI., was tested by Professor Kennedy, with the results given in the appendix.

The Normand boiler, shown in Fig. 9, Plate XI., possesses some of the peculiarities of both the Yarrow and the Thornycroft types. It will be seen that all the tubes are more or less curved, that external "down-comers" are used at both ends, and that all the tubes discharge into the upper drum below the water level. In an earlier form of this boiler, the tubes discharged above the water level as in the Thornycroft, but this arrangement was abandoned, I am informed, mainly on account of the external corrosion at the upper ends of the tubes, due to the low temperature of the gases there, and to the deposit of ash.

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Fig. 10, Plate XI., is a section of the Oriolle boiler. Some of the inclined tubes are above the water level, and the steam is collected near the top of the back water chamber by the pipe shown. When in action, part of the front chamber will be filled with foam, and there will be a continuous flow of water down the upper layers of inclined tubes to the back chambers, and up through the lower tubes from the back water chamber to the front one. With tubes 2 inches in diameter, the circulation through the tubes is said to be so vigorous that no deposit takes place in them, even if the water be impure.

In the Du Temple boiler, shown in Fig. 11, Plate XI., the lower portion of each tube is made of smaller diameter, so that the velocity of the water, or steam and water, is considerably greater in this, the hottest part, than in the cooler parts above. External "down-comers" at both ends ensure a free and upward circulation in all the tubes. The method of connecting the tubes to the drums is shown in Fig. 11, A.

THE STIRLING BOILER.

(See Fig. 12.)

This boiler consists of one water-drum connected by three series of sloping tubes to three steam drums. The drums are placed transversely, and the three upper, or steam drums, are connected by short curved tubes. The fireplace is immediately in front of the lower, or water drum, and baffle plates are provided to deflect the gases on to each series of tubes in turn. The feed water is supplied to the upper drum most remote from the fire. The ends of the tubes, which are all below water, are simply expanded into the drums.

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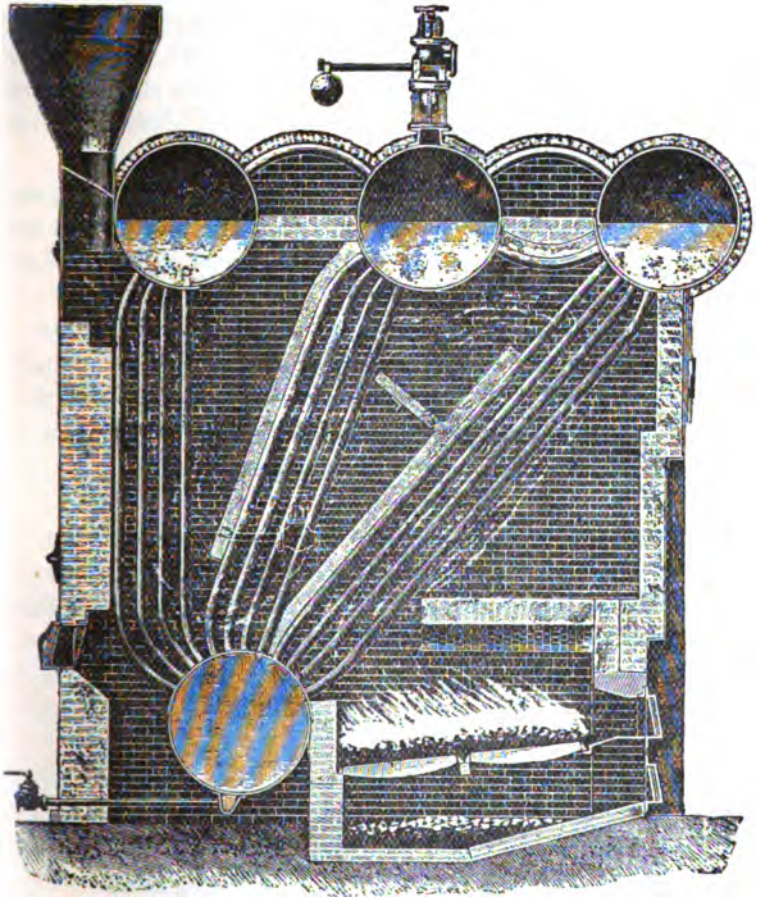
Fig. 12.



225 horse-power "Stirling" boiler.

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The advantages of the water tube boiler over boilers of the tank type may be summarised as follows:—

1. It is safer at all pressures, and much higher pressures may be used with it.
2. It is lighter, and can be made less bulky; its shape can also be better adapted to suit the space it has to occupy.
3. It is more portable, and can be got into places where ordinary boilers would involve great difficulty and expense to get in.
4. Steam can be got up much more quickly, and with some types the thermal capacity of complete boiler and water is only a small fraction of that of ordinary types, so that the loss due to steam raising is much less.
5. It may be made to be at least as efficient as other types.
6. Its life may be expected to be as long as that of any other type. There are water tube boilers of the Babcock & Wilcox type which are still in good condition after twenty-five years of regular work.

In conclusion, I would venture to say that although water tube boilers for marine work may not, at present, be greatly, if at all, superior, except for special purposes, to boilers of the ordinary type, they ought, on account of their great possibilities, to have every consideration.

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APPENDIX.

Report on "Clyde" Water Tube Boilers.

Copy.

S.S. "Aberdeen,"
Georgetown, P. E. Island,
October 25th, 1894.

Messrs Fleming & Ferguson,
Shipbuilders and Engineers,
Paisley.

Gentlemen,

I have now pleasure in sending my report of the "Clyde" water tube boilers and quadruple engines fitted in the S.S. "Aberdeen" for Canadian Government. The experience I have had of these engines and boilers is the several trips on Clyde, voyage across the Atlantic, and two months' service on the coast here.

During this time I have found supply of steam from these boilers to be at least one-fourth more than I would have got out of ordinary boilers on the same consumpt and on the same conditions.

The draught is all that could be desired, and during half the time on the voyage out, and since, I have run with ventilators turned with backs to the wind.

I have no difficulty whatever in keeping boilers in order, either inside or outside, and have got up steam on them from cold water easily inside of two hours, and steam could be got up in even much less time without least injury to the boilers. There has not been a single leakage on boilers since we left Clyde, and they have never required to be touched with a caulking tool.

Regarding regulation of steam no trouble whatever appears in keeping it quite under control. We have run 10 days without requiring to clean soot from tubes, although the coal we have been using has been very dirty indeed.

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When firing is properly regulated I have found boilers give very little smoke. Regulation of feed water has not given me least trouble, and have found it not necessary to touch regulating cocks for 6 hours at a time.

I have not seen a sign of water passing to engines even when the gauge glass was within 1 inch from top and ship rolling heavily. The boilers are perfectly stiff in ship, not a sign of movement having taken place. The examination of inside of boilers is so simple that I have been able to look at them often, and have found no difficulty in keeping them right, no sediment whatever lying where fire acts; firing with these boilers is also much easier on account of furnaces all being on one level.

The engines have worked without a hitch and have not given the least trouble. In fact, since we left I have had almost nothing to do to them, and the machinery department altogether makes a very comfortable job.

The steamer has been visited by a number of Government officials and engineers, and all have expressed their satisfaction with what they have seen.

I am,
Sirs,
Your obedient servant,
(Signed) Robert Hodgert,
Chief Engineer,
S.S. "Aberdeen."

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Log of steamship "Nero."
Fitted with Babcock & Wilcox Water Tube Boilers, as shown in Fig. 2, Plate IX.
Engineer's report of a voyage from Hull to Stockholm and back, commencing Sept. 7th, and terminating Sept. 27th, 1894.

	Outward Passage.			Homeward Passage.		
	Name of Port.	Hour.	Date.	Name of Port.	Hour.	Date.
		a.m.			a.m.	
Fires lighted at -	Hull	8-45	7th	Stockholm	6	22nd
Steam up at -	,,	10-15	,,	,,	7-30	22nd
Steamed ahead at and came to anchor in river - -	,,	10-50	,,	,,	p.m. 1-10	22nd
Left port at - -	,,	7-15	8th	,,	1-20	22nd
		p.m.				
Arrived at - -	Stockholm	4-55	14th	Hull	1-20	27th
Done with engines	,,	5-30	14th	,,		

	Outward Passage.				Homeward Passage.			
	No. of hours.	Rate per hour.	Coals Burned.		No. of hours.	Rate per hour.	Coals burned.	
			T. C. Q.				T. C. Q.	
Hours steaming full speed -	152·53	6 cwt.	45 18 0		119·30	6 cwt.	35 16 0	
Do. half speed	2·27	3 cwt.	7 2		1·0	3 cwt.	3 0	
Hours steaming dead slow -								
Getting steam	½	20 cwt.	1 10 0		1½	20 cwt.	1 10 0	
Banked fires -								
Detention -	7·20	1 cwt.	7 2		1·50	1 cwt.	2 0	
Coals consumed in main boiler			48 3 0				37 12 0	
With donkey blr.	90	2 cwt.	9 0 0					
Discharg. homeward cargo -								
Steaming with donkey -								
Discharging outward cargo -					103	2 cwt.	10 6 0	

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11 days' cooking, warming, etc., at 2 cwts. per day—outward passage, 6 days 9 hours 45 minutes; homeward passage, 5 days.

Tons of coal consumed during passage—outward passage, 58 tons 5 cwts.; homeward passage, 49 tons, 5 cwts.

	Outward Passage.	Homeward Passage.
Quality of coal,	Fair	Fair
Average of coal per hour, main boiler only,	cwts.	cwts.
Revolution,	65	66·25
Steam pressure,	200	200
Vacuum,	25·5	25·5
Average temperature of circulation—		
Discharged water,	100 degrees	100 degrees
Feed water heater,	170·134	172
(If any) No. of inches water blown out in 24 hours,	6 inches	6 inches
Strength of water in ozs. per gall. (tried hot),	1/4/32	1/4/32
Engines, how working,	Well	Well

Average speed per hour, outward, 6·743 knots.
„ „ day, „ 161·83 „
„ „ hour, homeward, 8·625 „
„ „ day, „ 207 „

Average indicated horse power, 432·708

Very heavy head weather nearly all the passage out.

Fine weather homeward passage—

Consumption per day for total steaming, 7·25 tons.

Consumption per indicated horse power, 1·553 lbs. per hour.

Description of coal—

Total number of ash and clinker during voyage and weight of buckets — 250 buckets of ashes; average weight, 60 lbs.; 6·21 per cent.

Steaming distances—Outwards, 1035 knots.
Homewards, 1035 „
Total, 2070 „

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The following table gives the results of tests made by Professor inson of the Babcock & Wilcox boilers at the St. Pancras ctric Light Station :—

Heating surface,	1619 square feet.
Grate area,	30 „
Ratio of heat to grate surface,	53·9 to 1
Kind of fuel—Nixon's navigation steam coal.	
Duration of test,	5 hours.
Average steam pressure,	173·5 lbs.
Average temperature of feed water,	48 deg. Fah.
Pounds of coal fired,	2352
Pounds of refuse,	56
Pounds of combustible,	2296
Per cent. of ashes,	2·38
Coal consumed per sq. foot of grate per hour,	15·6
Total water evaporated,	22,925 lbs.
Average evaporation per hour,	4585 lbs.
Maximum evaporation per hour,	5160 lbs.
Water evaporated per square foot of heating surface per hour,	2·83 lbs.
Water evaporated per lb. of coal,	9·747 lbs.
Water evaporated per lb. of coal, assuming feed water at 212 deg. Fah. and at atmospheric pressure,	11·906
Temperature of boiler room,	61 deg. Fah.
Temperature of flue gases,	185 deg. Fah.
Force of draught in inches of water,	0·391

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Principal details of Belleville boilers on the **Messageries Maritimes** Steamers.

	Ortegal.	Sindh.	Australien.
Number of boilers, - - -	8	12	20
Grate surface, - - - sq. ft.	243	295	596
Grate surface, per I.H.P., - - ,,	·116	·123	·085
Heating surface, - - - ,,	7414	11,050	23,059
Ratio of heating to grate surface, -	30·5	37·46	38·7
Weight of water in the boilers at working level, - - - - - tons	7·4	9·6	20
Weight of boilers and appliances, ,,	180	190	280
Indicated horse power, - - -	2100	2400	7000
Area of grate in each boiler, - sq. ft.	30·4	24·6	29·8
Weight of boilers with water and appliances, per I.H.P., in tons,	·062	·08	·04

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Results of Tests of Thornycroft Boiler, made by Professor Kennedy.

	A	D	C	B	E
1 Date	21st Nov., 1888	26th Nov., 1888	24th Nov., 1888	22nd Nov., 1888	29th Nov., 1888
2 Duration	5 hours 2 min.	4 hours 57 min.	5 hours 9 min.	4 hours	2 hours
3 Atmospheric pressure	14·8 lbs. p. sq. in.	14·55 lbs. p. sq. in.	14·80 lbs. p. sq. in.	14·84 lbs. p. sq. in.	14·45 lbs. p. sq. in.
4 Boiler pressure	186·0 „ „	181·8 „ „	171·2 „ „	149·4 „ „	180·5 „ „
5 Boiler pressure (absolute)	200·8 „ „	196·3 „ „	186·0 „ „	164·2 „ „	194·9 „ „
6 Air pressure in stokehold	0·00	0·00	0·27 inch	0·49 inch	2·00 inches
7 Air temperature in stokehold	—	69·3° F.	71·4° F.	60·3 F.	62·1° F.
8 Total weight of coal put on fire	1,680 lbs.	1,054·5 lbs.	2,877 lbs.	3,575 lbs.	3,503 lbs.
9 Total weight of ashes	270 lbs.	233·5 „	197 „	—	192 „
10 Weight of ashes put back on fire	None.	233·5 „	170 „	None.	192 „
11 Coal burnt per hour	334 lbs.	203·3 „	559 „	894 lbs.	1,751 „
12 Area of fire grate	30 square feet	26·2 square feet	30 square feet	30 square feet	26·2 square feet
13 Coal burnt per foot grate per hour	11·1 lbs.	7·74 lbs.	18·6 lbs.	29·8 lbs.	66·8 lbs.
14 Total feed water used	—	11,291·7 „	30·141 „	34,332 „	31,109 „
15 Feed used per hour	—	2,281 „	5,852 „	8,583 „	15,554 „
16 Feed temperature	78·4°	76·3° F.	78·0° F.	83·8° F.	111·2° F.
17 Steam temperature	382° F.	380·2° F.	375·5° F.	365·5° F.	379·6° F.
18 Factor of evaporation	1·192	1·194	1·191	1·182	1·158
19 Water evaporated per lb. fuel (ash not re-used)	—	—	—	9·60 lbs.	—
20 Water evaporated per lb. fuel under ordinary conditions, with ash utilised	—	11·22	10·48	[10·2 „]	8·89 lbs.
21 Equivalent evaporation from and at 212° F., (ash not re-used)	—	—	—	11·35 „	—
22 Equivalent evaporation from and at 212° F., with ash burnt	—	13·40	12·48	[12·0 „]	10·29
23 Equivalent evaporation from and at 212° F., per lb. carbon, value in fuel	—	13·08	12·18	[11·7 „]	10·04

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Results of Tests of Thornycroft Boiler, made by Professor Kennedy.—Table I., continued.

	A	D	C	B	E
24 Temperature of gases in chimney -	474° F.	421° F.	540° F.	610° F.	777° F.
25 Air pressure in chimney - -	0·00 in.	0·00 inch.	+ 0·03 inch	+ 0·12 inch	+ 0·40 inch
26 Total heating surface - -	1837 sq. feet	1837 square feet	1837 square feet	1837 square feet	1837 square feet
27 Ratio of heating surface to grate -	61·2	70·1	61·2	61·2	70·1
28 Water evaporated per square foot of heating surface per hour - - -	—	1·24 lbs.	3·2	4·7 lbs.	8·5 lbs.
29 Mean rate of transmission of heat per square foot heating surface per minute -	—	23·8 th. units	61·0 th. units	89 th. units	158 th. units
30 Efficiency of boiler - - -	—	86·8 per cent.	81·4 per cent.	78·2 per cent.	66·6 per cent.

Table II.

1 Revolutions per minute - -	192·8	165·2	234·2	268·7	318·4
2 St. press. in h.p. valve chest above atmosphere	50·6 lbs. p. sq. in.	22·7 lbs. p. sq. in.	79·2 lbs. p. sq. in.	120·7 lbs. p. sq.in.	168·4 lbs. p. sq.in.
3 Mean pressure, h.p. cylinder - -	17·6 ,,	13·0 ,,	27·3 ,,	37·6 ,,	49·9 ,,
4 Do. m.p. do. - -	13·7 ,,	9·5 ,,	20·1 ,,	27·2 ,,	40·2 ,,
5 Do. l.p. do. - -	3·4 ,,	2·2 ,,	5·74 ,,	8·29 ,,	12·8 ,,
6 Mean vacuum - - -	28·04″=13·77 lbs.	27·97″=13·74 lbs.	28·34″=13·92 lbs.	28·06″=13·78 lbs.	25·25″= 12·4 lbs.
7 Indicated horse power, h.p. cylinder -	41·7	26·5	78·4	124·1	195·3
8 Do. m.p. do. -	66·8	39·6	118·1	185·1	323·6
9 Do. l.p. do. -	41·8	23·0	85·0	140·0	255·8
10 Do. total -	150·3	89·1	282·1	449·2	774·7
11 Total feed water per I.H.P. per hour -	—	25·6 lbs.	20·74 lbs.	19·1 lbs.	20·08 lbs.
12 Jacket water per hour - -	151 lbs.	126 ,,	236·5 ,,	188·5 ,,	292·5 ,,
13 Jacket water per I.H.P. per hour -	1 lb.	1·43 lbs. = 5·6 p.ct.	0·84 lbs. = 4·03 p.ct.	0·42 lbs. = 2·2 p.ct.	0·38 lbs. = 1·9 p.ct.
14 Added feed water per hour - -	81·7 lbs.	12·9 ,, = 0·57 p.ct.	44·6 ,, = 0·76 ,,	88·2 ,, = 1·03 ,,	145 ,, = 0·93 ,,
15 Lbs. of fuel per I.H.P. per hour -	2·22 ,,	2·28 lbs.	1·981 lbs.	1·99 lbs.	2·26 lbs.
16 Lbs. of carbon value per I.H.P. per hour	2·28 ,,	2·334 ,,	2·03 ,,	2·04 ,,	2·318 ,,
17 Approximate speed of vessel on measured mile	11·8 knots	—	—	—	—

Table III.—Results of Evaporative Tests of various kinds of Water Tube Steam Boilers.

Description of Steam Boilers.	Area of Fire grate in square feet.	Total heating surface in square feet.	Description of Coal used.	Coal consumed per square foot of firegrate surface per hour in pounds.	Water evaporated per pound of coal from and at 212° F. in lbs.
Thorneycroft's water tube boiler - -	22·7	1410	Welsh	7·74	13·40
Babcock & Wilcox's do.	25	1403	Scotch coal	13·4	12·38
Do. do.	25	1403	,,	12·8	12·05
Do. do.	31	1380	Anthracite	12·8	11·22
Do. do.	23	1193	Steam coal	13·7	10·70
Do. do.	31·1	1426	Coke	6·8	10·05
Do. do.	25	1610	Welsh	23	10·00
Do. do.	15	860	Slack	24·6	7·20
Belleville water tube boiler	39·7	1264	Welsh	—	11·71
Do. do.	39·7	1264	Briquettes	—	10·83
De Naeyer water tube blr.	40	1700	Bituminous	14·25	11·70
Root's water tube boiler	27	875	Anthracite	11·7	10·60
Do. do.	36	910	,,	10·1	10·20
Do. do.	50	1440	,,	10·0	9·50
Do. do.	16·0	845	Slack	28·0	8·34
Buttner's do.	12·6	1942	Steam coal	31·0	10·50
Shepherd's do	26·18	529	,,	13·9	10·48
Do. do.	26·18	529	,,	12·9	9·98
Towne's do.			Coal	4·3	10·46
Harrison's do.	35·13	949	Anthracite	9·3	9·32
Perkin's do.	15·3	300	Semi-anthracite	12·0	9·27
Herreshof coil do.	26·0	485	Anthracite	13·0	9·10
Do. do.	26	485	,,	18·0	8·10
Heine's do.	19·4	869	Steam coal	18·8	9·00
Steinmuller's do.	32·3	724	,,	13·8	8·80
Watther's do.	15·7	996	,,	17·5	8·80
Neuman's do.	13·7	494	,,	14·5	8·70
Water tube boiler with vertical tubes -	21·2	928	,,	22·7	8·33
Water tube boiler with pendent tubes -	19·6	958	,,	21·9	8·10
Water tube boiler with vertically inclined tubes	28	1600	,,	20·7	7·34
Do. do.	17·3	870	Slack	34	7·02
Ward's water tube boiler			Coal	15·5	8·28
Water tube boiler on Root's principle -	33·2	1276	Steam coal	19·9	8·17

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Table IV.

Results of Experiments made with Lagrafel-D'Allest Boilers under the Direction of French Naval Officers, and of Representatives of the Forges et Chantiers de la Méditerranée.

	Trial No. 1.	Trial No. 2,	Trial No. 3.
Date of trial	June 29, 1892.	July 2, 1892.	July 6, 1892.
Duration of trial...	6 hours.	12 hours.	6 hours total.
Weight of Cardiff coal burned during the trial	4,500 kilos.	5,400 kilos.	2,700 kilos. during 1st 3 hours. 3,375 „ „ 2nd „
Do. per square metre of grate per hour... ...	100 kilos.	60 kilos.	120 „ „ 1st „ 150 „ „ 2nd „
Water evaporated during the trial	44,125 litres.	54,370 litres.	25,654 litres „ 1st „ 31,169 „ „ 2nd „
Do. per hour	7,354 litres.	4,530 litres.	8,551 „ „ 1st „ 10,389 „ „ 2nd „
Do. per square metre of heating surface ...	29·41 litres.	18·12 litres.	34·2 „ „ 1st „ 41·55 „ „ 2nd „
Do. per kilo. of coal ...	9·80 litres.	10·068 litres.	9.501 „ „ 1st „ 9·235 „ „ 2nd „
Temperature of feed	48·75°C.=119·75°F.	51° C. = 123·8° F.	52° C.=125·6° F. mean during both periods.
Do. of evaporation	194° C. =381° F.	194° C. = 381° F.	194° C.=381° F.
Evaporation from and at 212° F.	11·25	11·51	10·85 during 1st 3 hours. 10·54 „ 2nd „

Note.—The Author is indebted for some of the above tables, and for some of the matter in the paper, to the excellent papers on the subject by Mr Milton, also to the works of Hutton and D. K. Clark on Steam Boilers, and to the various manufacturers of water tube boilers, for information kindly supplied.

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The discussion on this paper took place on 26th February, 1895.

Mr CARLILE WALLACE said he had read this paper with great interest. It was one of those subjects which was now before the minds of all engineers, both marine and electrical, and in fact all those connected with the production of steam. He thought they were very fortunate in having in their midst a gentleman who had taken pains in making these experiments in the way Professor Watkinson had done, by constructing boilers in glass tubes and seeing what went on inside under the different arrangements of the tubes. As a rule, engineers had not the time, or perhaps the patience, to carry out experiments of this kind, and very often on that account they arrived at their results from actual practice, with repeated failures, often entailing great expense. One of the points he would like to refer to was where Professor Watkinson spoke of raising the temperature of the water to a pressure corresponding to 500 lbs. That meant a temperature of 460 degrees Fahrenheit. Further on, Professor Watkinson spoke of raising the water to the critical condition—that was the point at which it would all flash into steam, and he gave there a pressure of 3000 lbs. and the temperature as 698. A little time ago he (the speaker) had been in conversation with a gentleman who was connected with the manufacture of steel and had to do with steel furnaces, and he had mentioned that from experiments he had made the critical temperature of steel was when the steel had a temperature of between 450 and 600 degrees, and therefore he was pointing out that if it was the case that steel had this critical temperature, at which it was very much more brittle and liable to crack than at other temperatures if these pressures were used, then the tubes, if made of steel, would be in that critical condition. There was another point on page 142, in speaking of the Lagrafel D'Allest boiler, Professor Watkinson referred to the improvement made in the efficiency by altering the course of the gases. In all water tube boilers, and in boilers of all kinds, the greatest possible care should be taken that the gases were as far as possible consumed before they were brought into intimate connection with surfaces in the boiler surrounded

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with water, which reduced the temperature of the gases below the point at which they could burn, and they then passed over unconsumed. This constantly occurred when forcing marine boilers if the coal was bituminous. The flame being extinguished on entering the tube, it passed through them in the form of gas, and when it met the air at the smoke box end it burst into flame, causing the smoke box and funnel to become red hot. He believed the reason why the alteration in the Lagrafel boiler had such a beneficial effect in the evaporating efficiency of the boiler, was because the gases got more time to burn before they were cooled by the water in the tubes. Referring to the Scott boiler, it appeared to him that this arrangement would give a good space at the back for the mixing of the gases before entering between the tubes. Referring to the Thornycroft boiler, Professor Watkinson said, "With water entirely free from oil, it is possible to force this boiler to give 20 lbs. of steam per square foot of heating surface without overheating the tubes, but the introduction of a small quantity of grease caused the destruction of the tubes at this rate." It could not be because the oil was a non-conductor that it acted in this way. As he understood, the thinnest possible film of oil would cause overheating, and oil was not such a bad non-conductor as compared with other substances. He would be glad to know whether Professor Watkinson had made any experiments in this direction. He did not think there was anything to add except that the cost of water tube boilers was one point very much against them, as compared with the price of the ordinary return tube marine boiler; and, until the prices could be reduced, he did not think the use of the water tube boiler would become general, unless in cases where reduction of weight was of vital importance, as there were many advantages in the Scotch marine boiler not possessed by the water tube boiler.

Mr ANGUS MURRAY said he would like Professor Watkinson to give some information as to what he meant when he said, "It is sometimes maintained that as the average density of the substance in the tube, B, Fig. 1, is less than that of the substance in

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tube, A, etc., a circulation must take place in virtue of this. This is quite incorrect, as the hydrostatic pressure at bottom of tube, B, must be just equal to that at the bottom of tube A, so long as the continuity of the water is not broken in either of them. The absurdity of this theory of circulation is at once seen if we imagine a small cup inverted over each bubble of steam, as indicated at C, in the sketch." He could not agree with Professor Watkinson that the theory quoted was altogether wrong. They had no reason to imagine a cup placed inside of tube B to trap the bubbles of steam. If the flame or hot gases came in the direction of arrow at B, then circulation of the water did take place; the water in tube B being rapidly heated, expanded and rose, or floated up, imparting its heat by convection, and flowed into the upper drum. In this arrangement, the vertical tubes being small, the water thus rising upwards in tube B could only be replaced by a corresponding downward flow in tube A, while the rapidity of circulation depended very much on the difference of intensity of heat at B and A, but certainly was maintained by such an arrangement as indicated by sketch referred to.

Professor BARR thought that the paper was one of great value. He would like to ask what standard Professor Watkinson had taken on the top of page 134, where he said that if they had steam at 500 lbs. it would reduce the consumption below 1 lb. per indicated horse power per hour. That depended upon the standard with which they started. Perhaps Professor Watkinson might also explain a little more clearly what he meant by saying that pressures of 160 lbs. were advantageously used. Certainly they were advantageously used in locomotives, because it was troublesome to make a locomotive by any other system, but he did not think they could say that in a locomotive or any other engine such a pressure as 160 lbs. could be economically used in one cylinder, according to modern standards of economy of steam consumption. The next paragraph referred to superheating by expansion. He (Professor Barr) had not given this matter so much consideration as he knew Professor Watkinson had. The subject was an exceedingly interesting one,

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but he thought that this method of superheating was one that would not be generally adopted. He was very certain, however, that they were coming to the use of superheated steam. One of the greatest difficulties they had to contend with was the loss due to cylinder condensation, and anything that would get rid of that would greatly increase the efficiency of engines. Certainly throttling had sometimes the advantages that Professor Watkinson had spoken of, but he did not think that they would come to producing steam at very high pressures, and throttling it down to low pressures, because there were easier ways of accomplishing the superheating, without the dangers referred to in the paper. At the foot of p. 136 Professor Watkinson said, "In the case of most types of water tube boilers, however, rapid circulation is absolutely necessary, as by means of it the temperature of the boiler is approximately the same in every part, and if this were not the case leakage at the joints would inevitably result." That depended very largely on the design of the boiler, and all water tube boilers ought to be designed in such a way that the considerable differences of temperature would not produce leakage. Towards the foot of p. 137, Prof. Watkinson condemned very strongly one ordinary method of describing the nature or the cause of circulation in boilers. There he was condemning him (Professor Barr) among others, because he had used this mode of accounting for the circulation, and he intended to do so in the future. Professor Watkinson had appealed to the laws of hydrostatics, but he knew, without its being pointed out to him, that the laws of hydrostatics did not apply except when water was at rest. The water was not at rest in the tubes of the boiler, and therefore these laws did not apply. The action could be explained quite legitimately by saying that the presence of bubbles reduced the average density of the fluid. If he looked into the matter he would see that what he had said with regard to the hydrostatic law applied as legitimately to the gas in the bubbles as to the water surrounding them, and therefore the pressure at the bottom of the bubble would, according to that law, be greater than that at the top by only the pressure due to the depth of steam in the bubble, which

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was contradictory of the reasoning in the paper. There was a point at the foot of page 139 that he would like to refer to: "The size of the steam bubbles formed varies greatly with the rate at which steam is being generated. When the rate is great the bubbles are very much smaller than when the rate is very small. The size of the bubbles also depends, of course, on the pressure under which the steam is generated." He presumed that Professor Watkinson referred to the same *mass* of steam being produced. He did not know whether Professor Watkinson had any experiments to show that at high pressures there was a tendency, other things being equal, to the formation of smaller bubbles than would be formed at lower pressures if same *volume* of steam were being produced. On page 140 he said, "So far as the utilisation of the radiant heat from the solid fuel on the grate is concerned, the boilers with the tubes only slightly inclined to the horizontal have the advantage." He did not think that he could agree with him there, because even with a very much inclined tube (say the Yarrow boiler) he thought they could catch the radiant heat as well as with tubes less inclined. He further said, "In designing boilers of this type, especial care should be taken that none of the tubes act as condensers for the vapours in the products of combustion," but he would like to know whether that had occurred. He had not come across any cases where that had taken place. Then he said, "Boilers which are more triangular in form must occupy a greater space for a given power than those which are more or less rectangular in form." He was not quite certain that he could agree with that statement either. He had no doubt that a great deal of interesting information could be obtained from experiments such as that shown. He himself had intended to make experiments of that kind, and hoped to be saved some of the trouble by seeing what Prof. Watkinson had done so ingeniously, and with so much care and pains; but he could not say that he quite agreed with him that an experiment of this kind would be sufficient to show whether or not a "down-comer" was needed in a Yarrow boiler. He understood that Mr Yarrow had definite information from his own experiments on actual boilers that the "down-

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comer" was not needed, and he thought that where they had a much smaller volume of steam being produced per square foot of heating surface, and a very large number of tubes, the conditions might be very different from what they were in a small boiler such as this.

Mr JAMES GILCHRIST could not say that he had had any experience of water tube boilers, except one particular kind—the "Haystack;" but with reference to those boilers that were under discussion, it occurred to him that one of the most difficult things was the multiplicity of parts, and, at the same time, the costly nature of the manufacture. It was all very well for people like Professor Barr and Professor Watkinson to design a delightful boiler in theory, and bring it before this Institution for discussion, but when they took it into the workshop, among a lot of boiler-makers, it was a very different thing, and very different to make so many joints tight, in order that they might stand the necessary strain. So far as he had been able to learn, that had been the crucial point with reference to all water tube boilers, that while they were all right in theory, the difficulty was to make them so well practically, that they could stand up to their work. He was told that the most of the boats in the French service, using water tube boilers, had generally a considerable percentage of spare boilers on board to stand by. With reference to Prof. Watkinson's remark about 500 lbs. pressure, he quite agreed that it would be somewhat difficult to get the steel to stand. They would require to get some other material, because the crucial point of steel would be reached, and he would not like to be in the stoke hole when that pressure was on. As to the drying of the steam, which some of the gentlemen had been speaking about, marine engineers were not particularly anxious for dry steam, because, when they tried super-heating, they had a terrible job keeping their valves and valve faces in order, but when they had a very slight percentage of moisture the valves and pistons worked much more sweetly. From his experience in making many "Haystack" boilers, he thought the difficulty of getting at so many joints as were in those before them was quite apparent, and that those gentlemen who were engaged in

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the manufacture of water tube boilers, such as were represented by those sketches, must find out some other method of jointing than the system which was at present in vogue; because he felt quite satisfied that until these boilers were designed with a better arrangement for jointing, and more accessible for repairs, they would not become general at the present date.

Mr J. M. ADAM said that a few days ago he had had a communication from a friend in London who was bringing out a new water tube boiler, and when it arrived on the same day as the Transactions of the Institution it seemed rather a coincidence. He was further encouraged to make a few remarks by the last observation of Mr Gilchrist with reference to the jointing and keeping the tubes clean. In that connection he would refer to the paragraph that had been more than once mentioned, "In designing boilers of this type especial care should be taken that none of the tubes act as condensers for the vapours in the products of combustion." Mr Carlile Wallace also referred to the flame being extinguished on contact with cool surfaces, and he (the speaker) thought that remark might equally apply to water tube boilers. When the arrangement of the tubes was such in relation to the direct path of the gases that some of them or part of them were not exposed to the full heat, and when condensation led to encrustation, the question arose with reference to those boilers—especially to those having close starks of curved tubes, such as Fleming & Ferguson's and Thornycroft's—how were those tubes to be cleaned? It was obviously an easier thing to clean the inside of a cylindrical tube than the outside. That brought him to the new boiler to which he referred. The peculiar feature of it was that the tubes were compounded or arranged in groups let into a thimble or ferrule—groups of perhaps 7 or 9 having one common connection at each end with the drums, so that each group of tubes might be dealt with as a unit. Therefore an immense number of small tubes might be applied to the drums, with a comparatively small number of joints thereon, each compound tube being made and tested separately. In connection with that there was a cleaner or scraper

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applied to each group of tubes, something after the nature of Green's economiser, but worked by a simple rod and handle. A trial boiler of this type was now being built at Millwall, and he would be glad to give any further information to any member when it came to be tried, as it would be in a month or two.

Professor JAMIESON said, that he had not come there to discuss this paper, because he was sorry to say that he had been unable to find the time to read it. He had, however, much pleasure in drawing attention to a boiler invented by one of his students, Mr C. Scott Galloway. It had one benefit just mentioned by Professor Watkinson, namely, the down-comers. These were so arranged that the down-coming water was all discharged below the line of the fire bars, with an oppositely directed current of water at the same time taking place through the heating tubes. The boiler, although a water tube one, retained the best feature of the present type of marine boiler, namely—the internal furnace. The furnace gases flowed directly into a combustion chamber of ample size, wherein the smoke might be burned, thus leaving a clear incandescent flame to impinge at right angles on the surfaces of the short vertical tubes. The tubes were arranged so that there need be no difficulty in taking out or putting in one, without disturbing any of the others. All the tube ends could be got at by removing the manhole doors. The diagram on the wall (see Fig., page 167) showed a boiler with two 36 inch furnaces, which, together with the six feet fire bars, gave a total grate area of 36 square feet. The heating surface would be about 1600 square feet, and the weight, approximately, 30 per cent. less than that of an ordinary marine boiler of the same power. The design seemed to him to be well worthy of the attention of marine engineers, and he was glad to have had this opportunity of mentioning it before this Institution.

Mr GEO. CARRUTHERS THOMSON said he would like to know how the corrugated furnace tube in Mr Scott Galloway's boiler was riveted in place, and how it could be taken out in case of need for repair. As shown in the drawing it was practically impossible that the boiler could be made water-tight at the pressures it was

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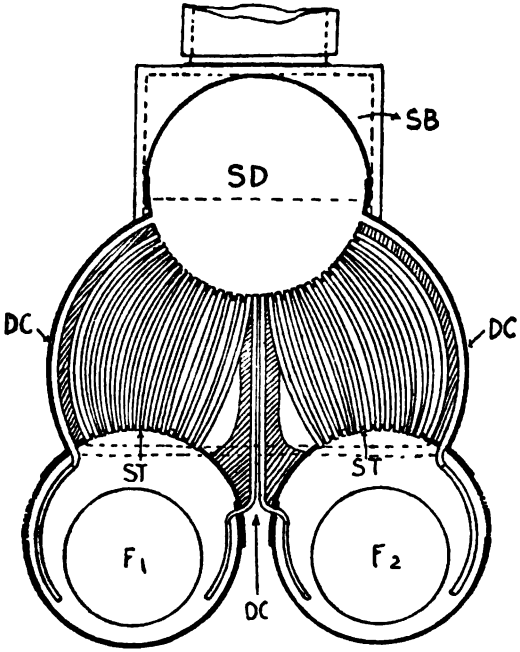

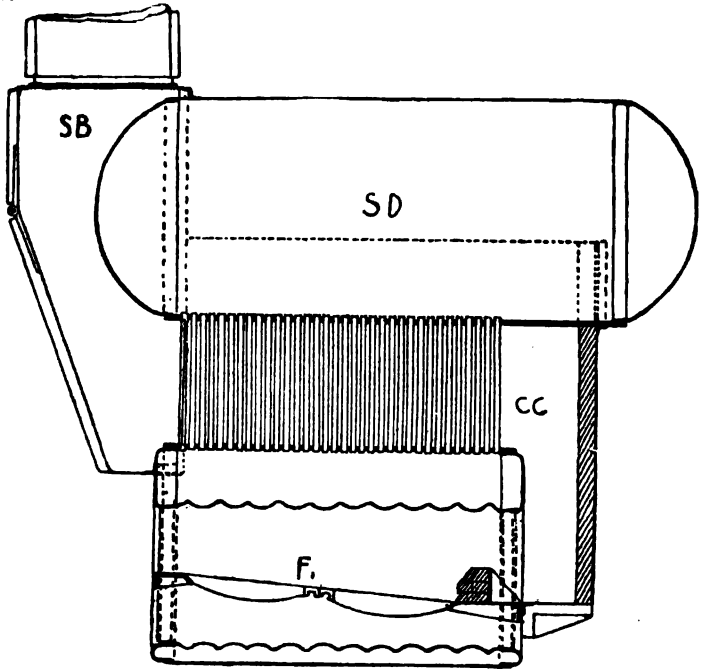

Index to Parts.

F 1 and 2 represents Furnace 1 and 2.
CC „ Combustion Chamber.
SD represents Steam Drum.
DC „ Down-comers.
SB represents Smoke Box.
ST „ Stay Tube.

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intended to be wrought at. With regard to water tube boilers, there was no doubt that they must be adopted if the pressures of 250 lbs. to 1000 lbs. per square inch were to be used in our steam engines, and also in cases where economy of space was a consideration; and it would be necessary to design them so that the circulation of the water would be rapid and constant, and that when steam was disengaged water should immediately take its place, otherwise there would be the danger of overheating the tubes. The use of steam at such high pressures when superheated presented no difficulty to lubrication that could not be overcome by the use of suitable lubricants. In reference to superheating it was certainly preferable to do so by wire-drawing rather than by the old method of the waste gases after leaving the boiler, and over which they had not such perfect control. It appeared to him that in a great many of the boiler designs shown, a vast amount of ingenuity had been expended in making the tubes of such a variety of shapes that it must be very difficult to make a good job of the boilers at first, and a great deal more difficult to repair in case of need, not to speak of the number of spare tubes requiring to be carried along with the boiler. In water tube boilers simplicity of design, ease of manufacture and repair, and durability, must be attended to if they were to supersede the popular and well-known forms of boilers presently in use. For speed in getting up steam they had no equals, but this very quality was against them when not carefully handled and the furnace doors left open too long. The details of the various tests given were very interesting, and would repay careful study. He had read the paper with great interest and pleasure.

Mr C. Scott Galloway said that he did not know that he had anything to say with reference to Professor Watkinson's paper, but he had some interest in the diagram on the wall. Mr Thomson had said he did not understand it, and had spoken about the corrugated flue. He had thought it was clear enough, but he would be glad to explain it.

Mr Thomson—How do you get it inside?

Mr C. Scott Galloway explained that the furnace was fitted to

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the back end, placed in position, then the front end was riveted to furnace and shell plate. Also, that the tubes were all expanded with the exception of the row on the centre line, which might be screwed, as shown on the diagram. The cleaning of the tubes could be done very much in the same way as with an ordinary boiler, because they were in straight rows, and a brush could be put through between the different rows of tubes. The outer row on each side, and the two central rows (which were down-comers), could be put into position from the outside. All the tubes between the fire-brick coverings were of such a length as would come inside the steam drum. The holes were bored in all the three tube plates radially to the centre, and the tubes, although bent, were put into their places as if they were straight.

Professor WATKINSON said he was considerably disappointed with the discussion, and thought that this was a subject which should have been discussed with great vigour in a society of this kind. Mr Carlile Wallace had referred to the critical condition of steel at the temperature mentioned as being necessary for those high pressures. He had considered that point carefully, in connection with the data he had available, before committing himself to the suggestion of the pressures mentioned, and he came to the conclusion that although the steel was certainly weaker at these high temperatures, the diminution of the tensile strength was not so great as to necessitate the thickness being greatly increased to give the strength necessary. With regard to the action of oil on the heating surfaces, Professor Lewes, some time ago, communicated a paper on the subject to the Institution of Naval Architects, and those wishing for full information should refer to that. He might, however, explain briefly that if they had oil in the water, and also some suspended solid matter, the little solid particles became coated with films of oil, and along with these the oil was carried down, and deposited on the heating and other surfaces. When the scale thus deposited became overheated, the oil was distilled off, and they had left a very porous deposit, which was an exceedingly bad conductor of heat, and overheating of the surfaces was the result of

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this. Mr Murray had referred to circulation, and to Figs. 1 and 2, page 138. Professor Barr had also referred to these Figs. (Professor Watkinson then explained the causes of circulation by means of sketches on the black board, similar to those given on page 138.) Replying to Prof. Barr's objection to the statement on page 137, that the hydrostatic pressure at the bottom of tube B must be equal to that at the bottom of tube A (Fig. 1, p. 138), the author said that it was quite true that the water was in motion, but its velocity was too slight, under the conditions assumed, to appreciably reduce the pressure at the bottom of tube B. The mere presence of the bubbles of steam, although they reduced the average density of the substance in the tube, did not on that account, as was often imagined, cause circulation. This was clearly seen by imagining cups inverted over each bubble, then, no matter how much steam there might be present in tube B, so long as there was no break in the continuity of the water, the pressure at the bottom of tube B would be approximately equal to that at the bottom of tube A, and, therefore, no circulation could take place. The only cause of circulation, under the conditions represented in Fig. 1, was as stated on p. 137, the entraining action of the bubbles of steam rising through the water.

Professor BARR—If you have got a bubble that fills the tube, then you can have no downward circulation of the water, and you must have an upward circulation. The reason why you don't get a brisker circulation is that you have a power for taking it downward, but if you put in those cups you have the hydrostatic pressure at the bottom.

Professor WATKINSON—Yes; when the bubble fills the tube the circulation is, of course, due solely to the difference in the average density of the two columns shown in Fig. 2, p. 138 of the paper. In calculating the decrease in coal consumption due to increase in steam pressure he had assumed a consumption of 2 lbs. of coal per indicated horse power per hour when the pressure was 80 lbs., and he thought that was a fair average result. Professor Barr had referred to another statement—viz., "that circulation was absolutely necessary

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with some types of boilers, otherwise leakage would take place." They must arrange, by means of a vigorous circulation, to have the temperature practically the same throughout, otherwise with straight tubes they would have so much straining that leakage would inevitably result. He might here refer to a remark made by Mr Gilchrist, "that in some water tube boilers leakage took place at the joints, and was one of the great difficulties." In most cases, where these leakages were not due to bad workmanship, they were due to the differences in temperature as referred to above, and they might be prevented by a more rapid circulation of the water through the tubes. He fully agreed with Mr Gilchrist's remark with regard to the means of connection. The expanded joint must go if they were to greatly increase the steam pressures. A boiler which would give dry steam at the normal working pressure, might prime very badly indeed when the pressure was greatly reduced, if the weight of steam generated in a given time remained the same.

Professor BARR—That is not with the same volume of steam, but with the same weight of steam.

Professor WATKINSON—Yes, the greater the pressure the less the volume of a given weight of steam and the smaller the bubbles formed. It was also important to note that the greater the rate of generation of steam, and therefore the more vigorous the circulation, the smaller the bubbles became, unless each bubble filled the tube, as in Fig. 2, page 138. That was seen very beautifully in connection with these experiments. When they put out the light the rate of generation fell very rapidly, and just at the last the bubbles were usually an inch or more in diameter in the larger tubes. With regard to the space occupied he thought that Professor Barr had misunderstood his point in connection with this matter. If they had boilers approximately triangular in form they had all the space between the two boilers wasted, whereas with boilers rectangular in form they had no space wasted analogous to that. Therefore he said, that other things being the same, boilers which are rectangular in form must occupy less space, for a given power, than those which were more or less triangular in form. The radiant

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heat in the rectangular boiler was better utilised than in the triangular boiler, excepting, of course, those boilers in which the furnace was surrounded with tubes, not only at the sides, but at the ends also. As most boilers had not their furnaces so surrounded, the general statement made in the text might be taken as true for almost all boilers in actual use. Then with regard to the down-comers, the glass model was not of course the full size; the tubes were about half an inch in diameter in this case and about 2 feet long, but he thought the action in boilers of the Yarrow type was shown pretty truly, and the down-comers seemed to be of real service. Thanks to the generosity of Messrs Babcock & Wilcox they had just had put into the author's laboratory at the Technical College a good large marine boiler, and he would be glad to show to any of the members interested in the subject both it and the models which he had shown to-night in operation. In his reply to Mr W. Carlile Wallace's question as to the effect of a little oil in the water, he had explained the matter in accordance with the results of Professor Lewes' experiments, but it occurred to him immediately afterwards that this explanation would not apply to the case mentioned in his paper, as in this case there was no scale, and there were no salts in solution or suspension in the water. He believed that the real reason why a boiler which might be safely forced to give 20 lbs. of steam per square foot of heating surface with pure water, would have its tubes burned in a very short time if a little oil were added to the water, was that the oil increased the surface tension of the water, with the result that the ratio of steam to water in the tubes was increased beyond the safe limit, and the tubes were overheated. The action was somewhat similar to that which would be produced if milk were used in the boiler instead of water. About six years ago he made a considerable number of experiments on the effect of oil on the water in a boiler, all of which led to the above conclusion, and it was strange that he should have forgotten to mention this when replying to Mr Wallace.

Mr F. J. ROWAN writes:—Having been unfortunately prevented by illness from taking part in the discussion of this paper, I wish to

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communicate the following observations upon it to the Institution through the Secretary. Professor Watkinson's paper is, although interesting, somewhat disappointing from the fact that its title and opening sentences offer the prospect of a more general treatise on the special class of boilers dealt with. I venture to think that the paper would be more correctly entitled "On some Water Tube Boilers," because it is the fact that no notice is taken of the design and working of several interesting examples of such boilers, which were in reality the prototypes of these recent specimens. In those examples which are noticed, there is not a feature of any consequence that is not to be found already published and proved in the boilers of Perkins, Martin, Benson, Alban, Howard, Root, Watt, Ramsden, Rowan & Horton (of 1869), and Rowan (of 1876), and this list by no means exhausts the history of water tube boilers. The Du Temple boiler is excepted from these remarks because it is itself one of the older designs. Professor Watkinson will find the "two chief reasons" which he gives to justify a favourable opinion of water tube boilers advanced and pressed in many papers dealing with the same subject for at least thirty years back, with an added one which he does not give—viz., the largely increased area of heating surface obtainable in such boilers, which results in economy in the utilisation of the heat of the fuel which is used. My own interest in the subject dates from about 1860, and most of the elements of the matter are noticed in a paper "On the Design and Use of Boilers," which I communicated to the British Association in 1878, and which was subsequently published in *Engineering* during the same year. Passing over Professor Watkinson's remarks on wiredrawing and superheating, with which I cannot say that I agree, I should like to make one or two observations on his remarks on "circulation." I agree with him in the remark that "in the case of most types of water tube boilers rapid circulation is absolutely necessary," only I should have said "*all* types" instead of *most*, and should not have advanced all the reasons given by Professor Watkinson. In a properly constructed water tube boiler, there is not much fear of leakage at joints, but rapid circula-

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tion undoubtedly prevents solid deposits, as well as air, adhering to the tube surfaces. It also preserves the boiler from the shocks and strains which are frequently due to abnormal actions set up where uninterrupted circulation is made impossible. Professor Watkinson has, on page 136, clearly demonstrated why it is of the greatest consequence that only water should be in contact with the surfaces that are heated, but his remarks on inclined tubes, at page 140, show that he is not prepared rigidly to carry out this principle in practice. In all but practically vertical water tubes, the upper surfaces of the tubes, and not merely the headers, when steam is being generated, must be in contact with a much larger proportion of steam than of water. This is to some extent illustrated even by Fig. 3, on p. 138, and Fig. 4, on p. 139, and by Thornycroft's experiments, quoted on page 144. With reference to the movement of the water in circulation, I think Professor Watkinson has forgotten that it is practically impossible to maintain all parts of a boiler at the same temperature, and that although steam is being generated in a boiler, it does not necessarily follow that all the water is at the same temperature. The "difference in density, due to difference in temperature," is, therefore, never wholly absent as a cause of circulation, and, moreover, in all rapid steam generators, water is bound to be carried up into the steam space by the steam, even in addition to the quantity forming the films which enclose the steam, and make the steam bubbles, and all this water must be returned to a lower level. For these reasons, it is necessary to provide a channel for the return of the water away from the action of the hot gases, and, therefore, at a temperature slightly lower than that of the steam generating surfaces. The "method of heating water under high pressure," referred to on p. 136, by which all the water is to be heated to a temperature above that due to steam of a given pressure, without the formation of any steam until a reduction of pressure takes place, demands conditions impossible of realisation in any ordinary boiler. For such a result to be attained, the boiler would require to be absolutely full of water (from which all air had been removed), without any air or steam space, every portion of the boiler surfaces

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must be maintained at the same temperature, and the surfaces in contact with the water must be perfectly smooth and chemically clean. Were all this realised, even then the game would not be worth the candle. The examples of water tube boilers which are cited in the paper are interesting, but the results given do not surpass many which have been obtained with the original forms of several of these boilers. The designs of the Babcock and Wilcox, the Lagrafel-D'Allest, the Belleville, the Oriolle, and one of the Yarrow boilers, are merely the continuations of older forms of the same designs introduced in bygone years by Alban, Howard, Root, and others, whilst the forms ascribed to Thornycroft, Yarrow, Fleming and Ferguson, and Normand, are merely modifications of the triangular arrangement patented by me in 1876, and published in the Proceedings of the Institution of Civil Engineers, in May, 1878, and in the Transactions of this Institution, in November, 1879.

Professor WATKINSON supplies the following note, added March 21st :—A copy of Mr F. J. Rowan's letter has only just reached me, along with a note that the printing machines are waiting. On this account, I cannot give a full reply to Mr Rowan, but I would point out that when reading my paper before the Institution, I did describe and illustrate the interesting types of boilers which he mentions—viz., those of Perkins, Benson, Alban, Rowan, and Horton, etc.; but, as I have before mentioned, the Secretary was of opinion that these historical boilers need not be illustrated and described in the printed paper, as they would increase its bulk beyond the usual limits. Mr Rowan seems to believe that the proportion of steam to water in the tubes is less when the tubes are vertical than when they are inclined. This is a popular fallacy, which is completely disproved by my experiments, and it was for this reason that I put the maximum advisable inclination at 70 degrees. When the tubes are vertical the water cannot flow downwards past the steam as freely as it can when the tubes are inclined, as in the latter case we have approximately the equivalent of a tube of diameter equal to that of the major axis of the ellipse obtained by cutting the tube by any horizontal plane.

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Mr Rowan's statement that it is practically impossible to maintain all parts of a boiler at the same temperature is only true where the circulation is very sluggish, and where some of the elements are of large diameter, as in the case of the boilers of the "Propontis," for example. In nearly all the boilers illustrated in my paper, the temperature of the water is practically the same throughout, and the circulation due to difference in density of the water on account of the slight difference in temperature is very slight indeed. Mr Rowan says that the generation of steam from superheated water "demands conditions impossible of realisation in any ordinary boiler," and he specifies a series of conditions which he says must be fulfilled in order that it may be accomplished. I regret that I have not now the opportunity of discussing this matter fully, but I can only now say, without the slightest possibility of doubt, that not one of the conditions mentioned need be fulfilled, and if Mr Rowan, or any other member interested, will come to the Technical College, 38 Bath Street, I will show him the method in operation. This system has been recently applied on a large scale, and is in operation every day near London.

The CHAIRMAN (Mr H. A. Mavor, Vice-President) moved that they accord Professor Watkinson a hearty vote of thanks for his paper. He would emphasise what Professor Watkinson had said with regard to the generosity of the Babcock & Wilcox Company. He was specially interested in the Technical College as a governor, and he hoped that he was not out of place in saying that the kindness which had been shown by that firm might very well be emulated by other members of this Institution, and that there was plenty of scope in the wants of the Technical College.

The vote of thanks was heartily accorded.

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Address by Sir William H. White, K.C.B., etc., Honorary Member.

At the meeting held on 22nd January, 1895;

The PRESIDENT said they had taken advantage of a visit to Glasgow of their most recently elected Honorary Member, to ask him to honour them with his presence on this occasion, and he now introduced Sir William H. White.

Sir WILLIAM H. WHITE said—Mr President and gentlemen, it is a great pleasure to me to come here to-night and to see something of the practical working of this Institution. I did not know when the President was good enough to ask me to come that it was in his mind that I was to be asked to offer a few remarks. That was one of the pleasant surprises which he so much rejoices in. I should have thought, after what we heard in the earlier part of the evening, that as I am abroad I should be allowed a certain latitude, and not be asked to deal at short notice with technical matters before such a competent audience as this. But I am extremely glad to have this opportunity of publicly thanking the Council and the members of this Institution for having done me the honour of making me one of their Honorary Members. It is quite thirty years ago since I began to be acquainted with some of the work done by members of this Institution, or, perhaps I should say, speaking more correctly, by the members of the Institution of Shipbuilders in Scotland, whose transactions were then to me most valuable. Ever since that time, I have continued to get great benefit from the perusal, from time to time, of your proceedings. I was not aware—in fact it is impossible from the dry bones of any recorded discussion to gather any idea—of what is the spirit which animates you. There is a popular idea in the south that Scotland is not quite the chosen home of humour, but if your proceedings to-night in any way indicate what they ordinarily are, then I can

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only regret that I live so far away from Glasgow. After the labours of the day are over—and they are not always so pleasant or so profitable as we would wish—we are all the better not merely for joining in discussions, such as you carry on, but at times joining in a very hearty laugh. Here to-night, with the greatest good humour on all sides, and with the little sparring and flashes of humour which prevailed, I have found you entering into the spirit of the proceedings in a way that I wish was prevalent in all the technical associations with which I am connected. Gentlemen, in a place like Glasgow, and a district like this, you have a great many advantages over the central institutions, which naturally find their home in London. You are nearer to such a great variety of work and manufacture. You are in an atmosphere which is full of experiments and enterprise, so that it is not to be wondered at that this Institution keeps alive and flourishes. You touch so many things—you have all the branches of engineering to discuss. You have civil engineering, which, I suppose, was the basis of the Institution of Engineers as it originally stood; you have mechanical engineering, mining and marine engineering, and metallurgy. You have also electrical engineering—that very vigorous infant, which, I suppose, its professors say has practically grown to manhood in a phenomenally short time. Then, although I mention it last, but by no means least in this district, there is shipbuilding, which you have associated with the other subjects. Those of us who are not bred as shipbuilders delight to speak of shipbuilding as one of the branches of engineering; but we, who are bred shipbuilders, like to think of it as at least one of the oldest forms of engineering, which involves difficulties that will compare with those to be met with in any branch of engineering, and problems which increase in difficulty as we advance in the speeds and dimensions of the ships. In all those ways this Institution seems to me to be doing extraordinarily good work. The only thing that I should say regarding this great range would be—and, of course, in the presence of our respected President, as he will have an opportunity of adding a word after I am done—I speak with the greatest caution—is that any ordinary person

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filling the Presidential chair must often find it difficult to master all the subjects in the discussion of which you indulge. I remember reading a paper on an electrical subject—read towards the close of the last session. It contained the description and the discussion of an installation of electricity which was being carried out in Glasgow. It appeared to me to include very recondite matters, which even your President, well informed as he is, might not have fully understood. Perhaps he will correct me if I am wrong. It must be difficult for a President thoroughly to grasp all the branches of knowledge which are represented, and so ably represented in this Institution; but we shall agree that the breadth and scope and variety of the work done here must add to the success, the utility, and the endurance of this Institution. All these matters are so connected in modern practice that if one cannot attempt to grasp them all, he must be the better in his own line of work for having some knowledge of the others. We hear a good deal about the co-relation of the sciences. Those of us who have to do with the various branches of applied science know that there is also a strong connection and a mutual help in these various branches and in the various forms of engineering which are represented here. I would not weary you with any further remarks, but will only thank you again most heartily for the honour you have done me, in enabling me to number myself amongst your members. I give you my hearty good wishes once more for your success. I cannot sit down without referring to the fact, that much of the knowledge that I may have acquired, comes from the works of the man who was your first President—Professor Macquorn Rankine—whom I mentioned at the James Watt Anniversary Dinner, held on Saturday last; and it adds much to the honour you have done me, that I can number amongst my nearest and dearest friends your President, who in every way is a worthy successor of those who have gone before him.

The PRESIDENT said he was sure they were all much gratified by the presence of Sir William White on this occasion. With reference to the possible deficiencies of Presidents in their knowledge of the various subjects that came up there for discussion, it was almost

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impossible that any one man could master them all, but during the discussions he had always understood that the President's business was to "ride the whirlwind and direct the storm," and he was not expected to supply very much whirlwind himself. On occasions when electric subjects were up, it was quite evident that electric and other whirls went on without any assistance from the President.

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On "*Electrical Transmission of Power in Shipyards and on board Merchant Steamers.*"

By Mr W. Carlile Wallace.

(SEE PLATE XII.)

Held as Read on 22nd January, 1895.

Mr Thomas Richardson, in his Presidential Address to the North East Coast Institute, instances as a fact of great importance to large users of power, that Messrs Dorman, Long & Co., of Middlesbrough, had, on some of the outlying originally steam driven machinery, substituted electric motor driving, the current for these motors being supplied by a 50 horse power dynamo, driven by an ordinary horizontal engine, with the result that a saving of some 30 tons of coal per week was effected, besides dispensing with two Lancashire boilers and the necessary attendance. It at once occurred to the writer, that in no class of work more than in shipbuilding would benefit result from electric motor driving, and with this idea in view, he at once set himself the task of finding out, as far as possible, what had been done in this direction, and this paper is to some extent the result of these investigations.

After the very clear explanation of the principle of the dynamo and electric motor given by Mr Mavor in his paper, which is now in the hands of the members, it is unnecessary to enlarge on this subject.

It may be accepted as an indisputed fact that for long distances transmission of power, say two or three miles, no other system can compete, in point of economy, with electricity having a high E.M.F.;

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but, in the case before us, we have a totally different problem to deal with, namely, the transmission of power for comparatively short distances, say 300 to 400 yards, the current used being of comparatively low tension, probably not exceeding 120 volts, so that the same generating plant can be used for lighting purposes. Further, the loss by leakage through imperfect insulation is very much less than with high tension currents; naked overhead conductors can be used and there is no danger to life, in fact, as far as the latter point is concerned, as long as the E.M.F. does not exceed 500 volts, the effect of the current passing through the body would not be fatal. The condition of things that at present obtains in a shipyard, as is well known to my hearers, is this. There are a number of punching and shearing machines, bending rolls, and machinery of this class placed in light sheds, and for the sake of convenience, partly because the work of these machines is intermittent and partly because the shed is usually too light to carry shafting, these machines are driven by ordinary high pressure engines, with cylinders about 8-inch or 9-inch diameter, and generally devoid of lagging. The steam is supplied from a boiler often a considerable distance from the machines, the steam pipe in many instances running for some distance in the open air simply covered with non-conducting composition tarred to keep out the damp. Under these circumstances, it is needless to say, that the condensation is very great. We will take for example the case of a punch; the bulk of the work about a shipyard is, say $\frac{7}{8}$-inch holes in $\frac{3}{4}$-inch plate, and the actual power required to do the work at the rate of 30 holes in a minute is about 3 to $3\frac{1}{2}$ horse power, but as the machines laid down are usually capable of punching 1-inch to $1\frac{1}{4}$-inch holes in 1-inch plate (besides to provide for shearing, which may be carried on at the same time as punching), the cylinders are much larger than would be required for the average work, the result is that the steam is constantly wire drawn in ordinary work. The following are some tests (see table) carried out on a punching machine in the writer's works; the steam is taken from a boiler at 60 lbs. pressure, and is carried through a 5-inch pipe for a distance of 300 feet where

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it supplies two machines, and then for a distance of 130 feet where it supplies four other machines; the punch experimented on was one of the two first supplied.

Trial Results of Shearing and Punching Machine.

Boiler pressure, 60 lbs. Valve casing pressure, 46 lbs.
Loss of pressure in pipe, 14 lbs.

Work done when card taken.	Revolutions.	I.H.P.	Mean Press.	Initial Press.
Running light, - - -	51	0·761	5·16 lbs	11½ lbs.
„ „ - - -	84	1·24	5·1 „	12½ „
Punching 13/16-in. holes in 3/8-in. plate	284	4·64	5·66 „	20 „
„ 13/16 „ 1/2 „	200	4·86	8·4 „	20 „
„ 1 „ 15/16 „	285	8·15	9·77 „	27 „
Shearing 3/8-inch plate, - -	284	4·73	5·77 „	20 „
„ 1/2 „ - -	200	4·86	8·4 „	21 „
„ 15/16 „ - -	320	8·82	9·54 „	25 „

Engine cylinder, 9 inches x 9 inches. For diagram, see Fig. 2.

From this table you will see that the indicated power was about double the actual power required to do the work, or in other words, the efficiency of the machine and engine was 50 per cent. You will notice that the drop in pressure from condensation, etc., was 14 lbs., and taking all the facts of the case into consideration, the writer does not think he is overstating the case when he says that when doing average work, the engines driving the punches in shipyards generally are consuming from 80 to 100 lbs. of steam per one horse power, or from 160 to 200 lbs. per actual horse power as required to do the work, and the same will apply to the rolls and every other machine about the yard driven by an independent high pressure engine when the work is irregular. Now, if instead of driving these machines by steam, we substitute electric motors, the current being supplied by a direct driven dynamo and high speed triple expansion condensing engine, fitted with some efficient controlling gear, supposing, for the sake of argument, that we require the same

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equivalent indicated horse power delivered at the punches that the triple expansion engine requires, 15 lbs. of steam, and that the efficiency of the dynamo current and motor are collectively 75 per cent. (see table below), we get 15 lbs. + 33 per cent. = 20 lbs. as the amount of steam consumed by the engine to give an equivalent 1 horse power at the motors.

Distances up to 500 yards should have an efficiency of 75 per cent., the loss of 25 per cent. being made up as follows :—

Loss in main generating dynamo, ...	7 per cent.
Loss in mains, ...	3 „
Loss in motors, ...	15 „

If the motors are all small, say under 8 E.H.P., the loss will be greater.

This alone gives a very fair margin to work on in favour of motor driving, but there is still another advantage to be gained, namely, that the efficiency of the triple expansion engine is much higher than that of the separate engine on the machine, and that the horse power given out by the motor much more nearly agrees with the actual power required for the work than is the case when a high pressure engine is used. Through the courtesy of Mr Selby-Bigge (who has made a special study of this subject) and Mr Panton, general manager of Messrs Dorman, Long & Co., Middlesbrough, the writer is enabled to give you the results (see table) of the practical application of motor driving in the works of the above mentioned firm, in which the machinery is of very much the same class as in shipyards. In this case the generating dynamo is driven by an ordinary horizontal engine of a not very economical kind, so that the results obtained speak all the more in favour of motor driving.

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Table of Electric Motor Tests.

Description of machine.	Driven by Engine capable of indicating	Replaced by motor capable of indicating	Voltage at generator.	Current taken by motor.	Voltage at motor.	E.H.P. absorbed in doing work.
Group of machines, as under:—	H.P.	H.P.		Amperes.		
Two cold saws, Two ending machines, One sharpening machine	27	10½	120	70	115	10·7
Troughing straightening machine, - -	14	3½	120	12	118	1·9
Double-ended punch, punching 4 holes, one side and one other,	14	5	120	25	115	3·7
Straightening machine, all sections, - -	14	3½	120	15	115	2·3
Straightening machine, biggest sections, -	16	3½	120	35	115	5·4
Cold saw, 26 in. diameter,	9	3½	120	15—27	110	2·2–3·9

If we examine this table of motor tests we will see that it bears out to a large extent what the writer has said with regard to the size of the engines fitted to this class of machinery; roughly speaking, the power which the engines in column 1 were capable of indicating was about three times the E.H.P. absorbed in doing the work, as shown in column 6. Further, from column 6 we are enabled to tell exactly what consumption of steam on the main engine is required to do the work at the motor; thus the efficiency of a triple engine combined plant, that is to say, the efficiency of the engine and dynamo taken together under full load would be about 80 per cent., and if this engine requires about 15 lbs. of dry steam per I.H.P. the dry steam consumption per E.H.P. would be 18·75,*

*Extract from Professor Kennedy's report on test of Castle dynamo coupled to Willan's patent central valve engine:—"During the time when the condensed steam was being measured, the mean output was 1010·5 amperes at 120·2 volts, which amounts to 121·5 Kilowatts or 162·8 electrical horse power. The condensed steam amounted to 3314 pounds per hour, which corresponds to 27·3 pounds per unit, or 20·3 pounds per electrical horse

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the efficiency of the motor and circuit combined is, say 75 per cent. (this has been taken low as the motors are small, see table 4), therefore, 25 lbs. of dry steam will give one electrical

Table 4.—Efficiency of Motors.

For	3	horse	power	motors	an efficiency of 78	per cent.
,,	5	,,	,,	,,	80	,,
,,	8	,,	,,	,,	84	,,
,,	11	,,	,,	,,	86	,,
,,	16	,,	,,	,,	87	,,
,,	20	,,	,,	,,	87	,,
,,	40	,,	,,	,,	89	,,

horse power at the motor. The evaporative efficiency of the boiler should be about 7 to 8 lbs. of water per pound of good Scotch coal and when allowance is made for boiler and steam pipe losses this should work out about 3·75 to 4 lbs. of coal per E.H.P. That the electrical horse power is much more efficient for driving the machine than an equivalent I.H.P. in the high pressure engine cylinder is fully borne out by the results shown in the foregoing table of electric motor tests. It may be as well here to mention, that Mr Panton has informed the writer, that so pleased is he with the result of the first installation that he is now putting down a further installation of 200 horse power. There is still a further advantage to be gained by the use of electric motors, which it is hardly possible to estimate; the work of the machines in a shipyard is very irregular and intermittent, the machines sometimes requiring double the power to drive them than at other times, or one machine may be standing for a considerable time while work to a plate is being done

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power hour. The indicated horse power at the same time works out to 190·2, so that the combined efficiency of engine and dynamo (ratio of electrical output at terminals to indicated horse power) reaches the very high figure of 85·6 per cent. The steam used per I.H.P. hour works out to 17·4 pounds. All these figures represent, as will be seen, the working of the dynamo and engine at a load just below its nominal output, and he further works out the efficiency of the dynamo alone to be 95·6 per cent."

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another machine; in the case of a motor the current which it es is in exact proportion to the work to be done, when it stops current absolutely ceases and no portion of the power to produce s current is required. It is far different when steam is used, for matter whether the machines are running half-power or idle, ndensation and leakage goes on just the same. Besides, to keep the inders clear of water it is necessary to keep the engines running the time, generally at about 50 revolutions, and if we look back at st table we will see that this is equivalent to about ¾ horse power, nich at 80 lbs. of steam per I.H.P., require 60 lbs. per hour, or much steam as would be required to drive the machine electrically hen punching ⅜-inch plates.

With regard to the cost of substituting motor driving for the resent system, this would vary very much as to circumstances. he simplest way is that adopted by Mr Panton—namely, removing ne connecting rod of the engine and driving by means of a belt rom the motor on to the fly wheel of the machine (see Fig. 2); the onductors will not be an expensive item if carried overhead. As ome rough idea of what would be required in this way, a ½-inch opper cable will convey about 25 horse power 300 feet with an E.M.F. of 120 volts and a drop in pressure of about 4 per cent. Suffice it to say in connection with altering existing arrangements, the writer is given to understand that in 12 months the saving in coals, etc., paid for the experimental installation put down at Messrs Dorman Long's.

The cost of fitting up a new yard electrically driven should not greatly exceed the cost of the old system. The motors might be fitted on to the machine, cut or helical gearing being used instead of belt driving; the cost of conductors would be much less than that of steam pipes, much less boiler power would be required, and instead of having separate lighting plant, the same generating plant could be used. It might be considered necessary in large works to divide the generating plant into two units, so that in case of a break down the whole work would not be stopped; but the likelihood of such a break down is very slight indeed, and as proof of this, a large

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power installation in Herstal, near Liége, has now been running for three years, and until recently the entire work depended solely on the running of a 500 horse power dynamo and engine, both for light and power. About 2000 hands are employed at the works; the large dynamo has never been the cause of cessation from work for a single minute. Every electric motor in itself may be said to be a self indicating machine, as by reading on an ammeter and volt meter provided in connection with the motor, the amount of current and its E.M.F., you at once arrive at the power absorbed by the machine. and should the readings be at any time abnormal it at once points to something wrong with either the machine or motor. Then again, by placing an automatic recording ammeter in the main circuit you get a constant record of all the current being absorbed by the different motors, etc., over the yard. From this record by means of a planimiter the manager can get the daily or weekly mean current used for power and lighting, and from this check the coal consumption under the boilers.

Once electricity is introduced on a large scale into our shipyards, other uses than those already mentioned will suggest themselves, as boring out stern tubes, hoisting, drilling on board ship, deck planing, etc.

As regards wages, oil, etc., this would certainly be less than in the old system, fewer firemen would be required, the motors would require little or no attention, and with properly arranged lubrication, very little oil indeed.* As to upkeep, of this the writer cannot speak from personal experience, but he understands that the upkeep on an electric power installation already running a number of years and involving the use of a large number of motors and lamps, can be safely estimated at a little less than 5 per cent. The conductors will give much less trouble than steam pipes, and there is really nothing about a motor to go wrong except the commutator, but since sparking has been reduced to a minimum and the introduction of

* In respect to this, the Electrical Construction Co., Wolverhampton, state that the motors in their shop, fitted with automatic lubricators, run for months without attention.

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carbon brushes when higher tension currents are used (see Fig. 3), a commutator will run for years without renewal.

Mr Alexander Siemens, in a paper read before the Birmingham Association of Mechanical Engineers, on February 16th, 1894, instanced the case of a motor on an electric locomotive on the City and South London Railway having run 26,000 miles (the armature was then as good as when put in), and also spoke of another motor having run for 14 years.

The writer might further go on to point out from actual data, that even in workshops and factories electrical transmission of power will compete favourably with shafting and belting, although at first sight this may seem hardly possible, but as this is rather outside the scope of the paper he will content himself with mentioning one or two cases in point. Some little time ago, Messrs. Siemens Bros. & Co. fitted up their works at Woolwich with electrical power transmission, and in the first 12 months they showed a saving of £1200 over the old system in coal, oil, wages, and upkeep in a 1000 horse power installation. Then if we go to the continent we have the National Arms Factory at Herstal, near Liége; the Royal Arms Factory at Liége, and the Zinc Works of the Vieille Montagne Company, near Jemeppe, all showing a distinct saving over shaft transmission.* The writer thinks he has said enough to prove that electrical transmission of power is now beyond the experimental stage. He is speaking in the

* Extract from *Engineering Review*, December 20th, 1894.—"Electric motors for machine shops.—*Locomotive Engineering* (N.Y.) for November, in an article on this subject, states that among recent improvements carried out in the Baldwin Locomotive Works was the removing of all overhead shafting from the wheel shop, and the providing of each machine with an electric motor for transmission of the motive power. The improvement has greatly increased the output of work and has materially reduced the power required for operating the machines. Mr Vauclain estimates from the reduced coal consumption, due to the change from shafting and belting to electric motors, that the saving in power is about 40 per cent. One advantage is keeping the space above the machines clear of obstruction. A travelling overhead crane has been put in, which takes the work to and from the different machines, saving a great deal of time and manual labour."

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interest of economy. We have hitherto been far too lavish in the use of coals in our shipyards and iron works. The East Coast is waking up to this state of matters as is proved by what has been done by Messrs Dorman, Long & Co., and Mr Selby Bigge is now busy fitting up the shipyard of Messrs. Furnace, Withy & Co. with electricity. This yard will be entirely remodelled and driven exclusively by electric motors. He is also advising other shipbuilding firms on the same question. Are we on the Clyde to lag behind in the race? Let us look to our laurels, or perhaps when too late we may find we have lost a supremacy we can never regain.

The first part of this paper has already trespassed too much on the time of this meeting, but the writer cannot leave the subject without saying a few words as to the advantages to be derived from electrical transmission of power on board merchant ships, especially in passenger vessels, and he would ask you to bear with him for a few moments longer.

Much that he has said with regard to the extravagant use of steam by punching and shearing machines will apply to the winches, windlass, and capstans on board ship, as also the steering gear, and as all these machines could be quite as well worked by electric motors and at less cost, the writer thinks it is high time the matter received the careful attention of shipowners, shipbuilders, and engineers. Consider the immense advantage it would be to get rid of winch pipes on deck or along the side, with all the attendant evils of leaking joints, heat, and space taken up, and if they are placed below the deck a leak may damage cargo, or if passing through the passenger accommodation the heat may, in the tropics, make the rooms unbearable. Then again, what an advantage in a passenger ship is the absence of noise, as an electrically driven winch with properly made helical gearing will be noiseless as compared with a steam driven winch. All our best boats are now fitted with electric light; we have electrically driven fans for ventilation in many of them fitted by Messrs Siemens Bros. & Co. and Messrs Holmes & Co. of Newcastle. It is surely only a little step to enlarge the generating plant, drive it with the most

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economical class of engine, and work all the auxiliary machinery about the ship by means of motors. The French are now adopting electricity in their men of war for training the guns, bringing up ammunition, and all the work usually done by hydraulic power, and if electricity is reliable enough for this class of work surely it is reliable enough for driving winches, etc. Messrs Siemens Bros. have made electrically driven winches and exhibited one at the Naval Exhibition in 1891, but whether any have been actually fitted on board ship the writer is unable to say.

As to the cost of electric power installation on board ship, the first cost would probably be more than the present system, but the difference would not be very great, as the less cost of the conductors as against the copper pipes, covering stools, etc., would to some extent meet the extra cost of winches and generating plant, but the difference would be more than made up by the saving in steam and the advantages already pointed out.

In the foregoing paper the writer does not pretend to any originality. Much, if not all of what it contains will be known to many of his hearers. He has done little but collect information as to what has been done in low tension electrical transmission of power; but if the subject is considered of sufficient interest to elicit a discussion, he will feel amply repaid. He would like, before concluding, to thank those gentlemen most cordially who have so kindly furnished him with information for this paper.

Note.—Messrs. Crompton & Co., Mansion House Buildings, London, in their new catalogue, July, 1894, give some instructive information on electrical transmission of power, with rough estimates of cost of power installations.

The discussion on this paper took place on 26th March, 1895.

Mr W. CARLILE WALLACE said as it was some time since this paper had been before the meeting, he would like to make a few remarks before discussion. He had stated, on page 183 of his paper, that he believed the engines of a punching machine consumed from 80 to 100 lbs. of steam per indicated horse power. Since then he had calculated from the diagrams the amount of steam

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actually used in the engines, and found it to be from 70 to 80 lbs. per I.H.P. per hour, and to this would require to be added the condensation in the steam pipes, so he did not consider he had overstated the case. Another point in favour of motor driven machinery had been prominently brought before him by the recent severe weather which they had had—viz., the immunity from freezing—whereas with steam the greatest precautions were necessary to prevent this when the engines were in open sheds; this also applied to the auxiliary machinery on board ships, and in the case of one steamer which came under his notice in Dunkirk, it was necessary to keep the winches running night and day when unloading, to prevent them freezing; and in another instance in Liverpool, he found the winch cylinder covers and valve chests burst through carelessness in not properly draining them. With a large supply of current at command, there were many other uses to which electricity might be put, and among them that of electric welding. This latter might be advantageously resorted to for repairing purposes in the case of a break down at sea.

Mr WARD hoped that in about a year hence he would be able to supplement to some considerable extent Mr Wallace's hopes and fears in this direction. They had done a good deal in the use of electricity as a motive power in Dumbarton. The pattern shop in their engine works was driven by electricity, as was also the machinery in the experimental tank, carving, and upholstery departments of the shipyard. They had also used electricity for drilling engine seats, double straps on sheer strakes, round the stern frame bosses for shell plates, and also for the deck plating holes in steel decks for the bolts fastening deck planks. At the present moment they were fitting up a small electrical installation in connection with their punches, and some of the staff could either confirm or give their experience as to power necessary for successful working—based upon accurate information taken from the machines themselves—as the first step towards the organisation of a larger development along the line of ultimately driving their whole machinery by electricity.

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Mr ARCHIBALD DENNY said that he originally meant to read a paper on this subject, but thought that he had not sufficient data to prove of interest to the society, but if Mr Wallace was willing he would be very glad to seek such data for the power required to drive a punch, because that was practically all that he had done accurately, and he would be glad to send this to Mr Wallace if he chose to publish that in his paper.

Professor JAMIESON said it was very encouraging to those who had the training of numerous students in connection with electrical engineering, as well as to the students themselves, to see this new outlet springing up. He had read this paper in full detail to his senior day students, and they had discussed the subject in a private way. He had pleasure in telling them that he had received a letter from his brother (who was well known in connection with the Broken Hill Silver Mines), that he was busy initiating a 5000 horse power installation in connection with the electrical lighting and transmission of power in Australia, and that he had just seen a large plant that was sent out from this country, which plant had entirely replaced the previous shafting and gearing. He was very glad that Mr Wallace had referred to Siemens' case. He had seen the whole of the installation, and it was one of the first whereby it was clearly proved that under certain conditions the electrical transmission of power was much more economical than that of a continuously going engines and shafting. The case resolved itself to this, that if they had intermittent machinery such as punches and drills in shipyards, which were only required now and again, and which were a considerable distance from the boiler, it was far cheaper and handier to use electrical power. But, if they went to the other extreme and had a continuous load, and could use high-class engines and boilers, and if the distance from these engines and boilers to the several machines was not very far, then it was better to use them as heretofore. Mr Wallace must excuse his differing from him on p. 182. He there said—what was a common and current error amongst people in this country, although not in America where they had had a good deal of unfortunate electrocu-

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tion—"Further, the loss by leakage through imperfect insulation is very much less than with high tension currents;" that was very true, but then he said, "Naked overhead conductors can be used. and there is no danger to life." They could be used, but he (Prof Jamieson) would not say that there was no danger to life! They would require to be very careful in the use of bare wires conveying currents at a pressure of 500 volts.

Mr HENRY A. MAVOR was very glad that Mr Wallace had brought this paper before them, because he did not think there was a more fruitful field than the transmission of electrical power in shipyards, and Mr Wallace had proved that in his paper. With regard to the using of naked conductors, any money saved in that way was not well saved, because, although there was not any extreme danger in using them in that way, there was great inconvenience in bad weather. With regard to the steam consumpt, he did not wish to throw any doubt upon Mr Wallace's figures, but he rather feared that Mr Wallace showed somewhat too good a case for electrical transmission, particularly in the table of electric motor tests on page 185. The comparisons seemed to have been made in a somewhat unfair way to the steam engine. They had one prominent case where an engine capable of indicating 14 horse power was replaced by a motor absorbing 1·9 horse power. That comparison was a perfectly just one as a comparison of what was wasted in a shipyard with the steam engine, but it was not quite fair to blame the steam for it. It was the faulty design of the apparatus. At the same time there was no doubt that such data as given by Mr Wallace were of immense value to electrical engineers and to steam engineers, because they had the exact measure of the power, which would be impossible to obtain by means of indicator diagrams. Another point on which he was afraid he could not quite support Mr Wallace's calculations was with regard to the efficiency of the generating plant. He thought that a sufficiently good case could be made out for electric transmission without relying on the experiments he had mentioned. The very fact of the work being intermittent made it very difficult to estimate the consumption of

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coal, and it was within the experience of all who were using electrical generating plant that while such consumption of steam as 18¾ lbs. per horse power as Mr Wallace had given, and quite correctly given, was the record of experimental tests, still when the load was varying, and the work was carried out, such efficiencies were not obtainable in practice. That would be seen from the diagram on Fig. 4, where the efficiency curve dropped very rapidly after half load, and that indicated that the plant should be put in as small as possible, consistent with getting satisfactory work out of it. Then, another practical point in the application of electrical driving in shipyards was that it was a great mistake to mix up the lighting with the power transmission, because they would not get such satisfactory lighting arrangements if they did so. The arrangements were better to be quite distinct. An important point was brought out by Mr Wallace with regard to the possibility of getting an absolute check upon coal consumption from the electrical record. A meter could be placed which would show to a pound what was the coal consumption under theoretically perfect conditions, and the deviation from that was the margin of possible saving. There were many applications of electrical power in a shipyard which had been mentioned by Mr Denny and Mr Ward, but there was a new one which he knew was first applied in their yard and which Mr Denny had not mentioned, namely, the planing of ships' decks, and that had already been introduced on the Tyne as well as the Clyde, as likely to produce a very large reduction on the cost of this operation. Electrical welding was also a very important application which was likely to extend, but patent rights were held in this country by a powerful syndicate, and he was sorry to say it made the royalty so high that only one shipbuilder on the Clyde was making any practical application of it.

In answer to a question by Mr Denny—

Mr MAVOR said that his firm had been called in lately to report where a man had been killed under conditions where the pressure could not have exceeded 400 volts. It was quite impossible to say what would form a fatal shock. He did not make a practice of

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handling conductors where the pressure was over 100 volts. There was no danger up to 100 volts, but after that the shock might prove fatal to any man under certain physical conditions.

Mr SAM MAVOR said that there were one or two points that he considered Mr Wallace should note. Mr Wallace spoke of using a triple expansion engine for driving the generating machinery, but in view of the varying nature of the load he thought that a compound engine would be a more economical type of engine for the purpose. On page 183 Mr Wallace spoke of the loss of pressure in a steam pipe being 14 pounds in a length of 300 feet. Was not that a mistake, and was not the difference in pressure due to the throttling of the steam at the engine steam chest, and not loss of pressure in the pipe as stated? The loss stated would amount to 23 per cent. of pressure in a pipe 100 yards long, and it seemed a good deal too much. Mr Wallace's calculations as to efficiencies, given on pages 184 and 185, did not correspond. On his table of comparative results Mr Wallace spoke of the indicated horse power of electric motors, and that was rather misleading when put in a column adjoining one giving the indicated horse power of the engines. The power of the motor should be stated in brake horse power and compared with the brake horse power of the engines, which in small engines would be only about 80 per cent. of the indicated horse power. The expression "indicated horse power" was not applicable to an electric motor in any sense, nor was the electrical horse power delivered to the motor analogous to the indicated horse power of the steam engine, but to the energy as measured by the weight and temperature of the steam delivered to the engine.

Mr M'WHIRTER moved that the discussion of this subject be adjourned to the next meeting in respect to the lateness of the hour.

This was agreed to.

Mr WALTER DIXON writes:—

It is a subject to which I have given a good deal of attention, and his, together with the fact that I have myself seen most of the

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electric power installations to which Mr Wallace has referred, must be my excuse for making any remarks on the subject.

We are indebted to Mr Wallace for bringing this subject before our Society, and there can be little doubt that it is a matter which is destined before long to claim a good deal of attention.

Hitherto we have heard little of it on this side of the border, but an active interest has already been taken on the north-east coast, which interest has resolved itself into some very practical adaptations, of the nature of which Mr Wallace speaks.

Our attention during the last two meetings has been centred upon the question of the most economical type of boilers, or, in other words, how we can best reduce our coal bills; and in this sense the paper under discussion only seems a continuation of this subject, with this difference, that whereas we have been previously dealing with an important, but an already economical consumer, we are in the present instance dealing with an important but a very wasteful factor—viz., long and exposed lengths of steam pipes and inefficient engines. Mr Wallace has pointed out on p. 183 of his paper that he estimates that from 160 to 200 lbs. of steam is the consumption per actual horse power to do work under the conditions of which he is speaking.

During the last few days I have, in conjunction with one of the principal shipbuilders in the district, had the opportunity of confirming this figure, the results of our investigations being that 200 lbs. is not by any means in excess of the actual facts—250 lbs. would probably be nearer the mark.

Where such cases as this can be shown to exist, some new system is highly desirable, and there can be little doubt that the system which Mr Wallace has brought before our notice, and which is already in more or less extensive operation, is one which must claim the attention of those who, for their clients, are able with these inefficient methods to make machinery to indicate one horse power on, say, $1\frac{1}{2}$ lbs. of coal.

The installation at Messrs Dorman Long's has been referred to, and I can verify all that has been said of it; but would mention

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that one can hardly, without seeing it, appreciate the simplicity with which the whole system has been revolutionised from steam driven to electric power driven.

The fact that this plant is being largely extended, and that it has inspired several other large installations in the district, is perhaps the best proof of its satisfactory and economical working.

Mr Thomas Richardson, in his address to the North-East Coast Engineers, has made large reference to it, and in his further remarks before the Federated Institute of Mining Engineers, he again mentions this, and states that after carefully looking into the question, and extensive experiments, arrangements were gradually being made which would eventually result in steam power being replaced by electric power in the works with which he is connected. Mr Wallace has also referred to the shipbuilding yard of Messrs Furness, Withy, & Co.; but he has not mentioned what will, I think, in its way be probably the most important installation in this country, and which is at present on the eve of being fully set to work—namely, that of Messrs Bedson's wire works at Middlesbro'. After carefully inquiring and considering the various systems, this work has been laid out complete with electric transmission.

A 600 horse power triple expansion inverted engine has been put down, to which the dynamo is coupled direct, and conductors are led throughout the works to some 50 or 60 motors, which are working the various machines, including travelling and jib cranes, pumps, fans, lathes, etc.

Whatever the opinion of outsiders may be, the proprietors of this establishment do not seem to have the slightest doubt as to its success in all ways, nor does there seem any reason to anticipate anything but thorough success.

Practically speaking the matter, so far as shipyards, etc., are concerned, resolves itself into this: with a properly designed electric plant, an efficiency of say 65 per cent. to 75 per cent. can be obtained anywhere within a radius of say 500 yards from the generator; further, this efficiency can be maintained with very unequal loads, the power taken from the generator at all times being only propor-

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tional to the amount of work required to be done at the various motors. For constant running machines with steady loads and under favourable conditions, hydraulic and other powers may be more or less able to compete with this, but for works such as we are considering, we think that there is nothing at present shown to be equal to it.

Mr Wallace has also mentioned the installation at the Vieille Montagne Co., in Belgium, which I have also seen, and which, in its way, is very remarkable. In this case a 600 horse power compound condensing horizontal engine has been put down, with generator, and this at the present time is driving 45 electric motors, varying from 1 to 80 horse power. This installation has a total efficiency, including loss in steam engine, dynamo, conductors, and motors, of 68·5 per cent. It has replaced several scattered boilers and engines about the works, and about the economy there is no question. I understand arrangements are being made for putting down another 600 horse power plant.

The installation at the arms factory at Liége, which is mentioned also by Mr Wallace, has had an additional 300 horse power plant put down recently.

I think all these additions are very important and worthy of note, as showing that the plants are so far considered satisfactory.

With reference to the question of cost, Messrs Siemens have lately put down a large plant in their works equal to some 1400 horse power, employing 72 motors, and replacing 11 steam engines. Mr Alexander Siemens, in his paper to the Federated Institute of Mining Engineers, mentions that he has considered and compared the outlay for an electric plant and for a steam plant, and finds that the capital outlay for their installation is 30 per cent. higher than in the case of the old steam plant, for the new electric plant. This would appear to be a very important point, especially in the consideration of laying out of new works. Unfortunately, we are not so much interested in the laying out of new works as the best method of dealing with the old ones we already have. On this point, however, the matter assumes quite a bright aspect.

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I have gone into the matter both independently and at length with Mr D. Selby Bigge, who has already been mentioned as having given special attention to this matter, and it would appear that there is no question about the statements that have been made, that under certain conditions, which by no means rarely exist, old plants can be taken out and new plants put in, and the whole cost recovered in from four to five years. This I consider is an important fact, and from an economical point of view speaks for itself. If the shipyards on the north-east coast adopt this, there is little doubt that it will soon make itself felt in a tangible form. It is not only in the application of motors to outlying machines in which this power can be economically employed.

Mr Richardson, in his address previously referred to, has mentioned that various tests have been made as to the amount of power absorbed in driving shafting and gearing in workshops, and these vary from 42 per cent. to 75 per cent., or an average of 50 per cent. over several experiments which were made.

Bearing on this subject, Mr D. Selby Bigge has also pointed out a curious case, which, paradoxical as it may seem, turns out to be a fact—viz., that from several experiments which have been made in workshops, more power is absorbed in running the whole of the machines light than when the ordinary normal work is going on. Diagrams have been taken of this.

There can be little question that a judicious arrangement of motors driving sections of machines could be employed economically, as also the putting down of separate motors for special large machines, such as lathes, wall planing machines, etc. In the case of the arms factory at Liége already referred to, a 40 horse power motor is applied to drive each of nine or ten main shafts, from each of which a large number of small machines are run. I think it is more than likely that accumulators will also eventually be employed. By this means, in the case of overtime, where occasional work is required from various machines in the shops and yards, the necessity of keeping up steam and the various engine and boiler attendants would be obviated.

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With reference to the employment of electricity on board ships, this is fast coming to the front, and it is only a question of time when most of the auxiliary engines at present employed will be replaced by electric motors.

I am in communication with the chief engineer of one of the principal shipowning companies in Britain, and hope soon to have the result of experiments which have been made with an electric winch on board ship, and which I shall be pleased to put before the members of our Society.

I must apologise for these lengthy remarks, but the matter is an important one, embracing, as it does, the whole absorbing question of the nineteenth century—viz., economy and cheap production.

Mr F. J. ROWAN writes:—

The subject of Mr Wallace's paper is one in which I have taken great interest for some years. About the year 1886 several careful comparative estimations of the efficiency and cost of four different systems of transmitting power were made by M. Arthur Achard of Geneva, Professor Reuleaux, Professor W. Schulz, Herr A. Beringer, and Professor Perry. They compared electricity, hydraulic pressure, compressed air, and tele-dynamic cables or ropes, as regards—1, the useful effect of (*a*) the generator or prime mover, (*b*) the conductor or transmitting apparatus, and (*c*) the receiving motors; 2, the first cost of the system; and 3, the cost of maintenance. Beringer's comparison was especially complete, and it was awarded a prize by the Electro-technical Society of Berlin. Professor Perry did not go so fully into the matter, but gave calculations of the loss in horse power transmitted over distances ranging from 1 to 1000 miles, where from 500 up to 32,000 horse power were given in at the generator. He compared hydraulic transmission with pressures of 70 lbs. and 1400 lbs. per square inch, and pipes of 6 inches and 3 inches diameter, against electricity of 8000 volts and 80,000 volts potential, with wires of $\frac{1}{2}$-inch and $\frac{1}{4}$-inch diameter. The combined results of these comparisons showed that electrical methods must ultimately prevail; and as mining, on account of its long distances for trans-

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mission and its special requirements, offered a good field for the demonstration of the advantages of electrical transmission, I at once brought this subject before the Mining Institute of Scotland, and strongly advocated "The Application of Electricity to Mining," in a paper read before that Institute on this subject, in November, 1886. At that time there was only a solitary experiment in electric transmission, and that of very limited extent, carried out in any colliery in Britain; but in the course of three years I was able, in another communication to the Mining Institute, to point to several successful instances in which electrical plant had been set to work. Now there are many such in Britain, and Scotland has a small but by no means an insignificant selection of them.

For other branches of engineering and manufacturing work, the introduction of electrical methods on an extended scale has been a much slower process, but I have repeatedly expressed the conviction that it must come; and in describing my own electrical machine tools to the members both of the Institution of Mechanical Engineers, in August, 1877, and of this Institution, in March, 1888, I urged that the introduction of such appliances should be looked upon as merely the beginning of that order of things which would see electrical distribution of power carried out throughout workshops and yards, and taking the place of present systems of shafting and belts, or steam pipes or hydraulic pipes, used as power distributors. I am glad to see, from the accounts given by Mr Selby Bigge to the Iron and Steel Institute, and by Mr Wallace to this Institution, that the realisation of such improvements begins to loom so much nearer to view; and it is to be hoped that the results already obtained, both in England and on the Continent, to some of which Mr Wallace has drawn attention, will stimulate further advance in the same direction. There is no doubt that on the score of first cost, on that of efficiency and economy in transmission and utilisation of power, and on that of the excellence and completeness of its means of recording and checking results, an electrical system of transmission, properly carried out, has many and great advantages over all other systems. Where in addition it is possible to utilise

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some natural source of power, such as a fall of water, as the prime mover, the economy may become very substantial.

I must ask Mr Wallace to be kind enough to add "riveting" to his list of useful applications of electricity in shipyards, and also to suggest, in my interest, that every steamship carrying a dynamo should be equipped also with at least one portable electric drilling machine for the work of repairs on board ship.

To his list of works now making use of electric appliances on a large scale he should add the Bedson Wire Company of Middlesbro', the Clarence Iron Works of Messrs Bell Brothers & Co., Messrs Dietrich & Co. of Luneville, and the salt works of Val-St.-Lambert, as in all these there are successful applications of the system.

The discussion of this paper was resumed on 30th April, 1895.

Professor JAMIESON said he had put on the board a small equation.—When the prime cost, plus annual depreciation, plus interest, insurance, [and working expenses*] of an electric power plant equals the prime cost, plus annual depreciation, plus interest, insurance, [and working expenses*] of a steam plant, with steam pipes, belting, and gearing, then it is time to go in for the electrical transmission of power.

The PRESIDENT said he would ask if the annual depreciation, and interest, and insurance of anything were not a function of the prime cost, as a rule.

Professor JAMIESON—Most decidedly; but they are different functions for electrical and for steam plants.

The PRESIDENT said it seemed to him that the equation might be simplified a little.

Mr GALE said he saw that Professor Jamieson ignored water power in the equation.

Professor JAMIESON—It was not in the question.

Mr CARLILE WALLACE said that before replying to the discussion, he would like to say that Mr Selby Bigge was in the room, and as he had had more to do with that class of transmission perhaps

* The parts within the brackets were added since the meeting.

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than anybody else, some of the members would be glad to hear him on the subject.

Mr SELBY BIGGE, on rising to reply, said that Mr Wallace had alluded in far too glowing terms to the little he might have done in developing electric power applications in this country. He certainly, during the last four years, had been exclusively engaged in applying electricity for power purposes, and applying it to very varied kinds of work and different industries. From what he had gleaned from the printed discussion on this paper, it seemed to him that the impression had been left on the minds of most people in the Institution that electricity as a power was quite in its experimental stage. He would like if possible to prove to them that electricity had passed far beyond this stage, and was now looked upon as a recognised means for conversion of power and its transmission under particularly advantageous conditions. He had recently been officially connected with various installations which Mr Wallace had referred to in his paper, amongst which was the application of motors in shipyards, iron and steel works, engineering works, textile factories, and factories generally, and he could truly say that in every case where electric power had been so far applied, without a single exception, the power had been extended by those people who had adopted it of their own free will. Why had they done this? They had not done it from any philanthropical motives towards electrical engineers. They had done it simply because they had saved money and economised, and it was solely upon this score that he would ever ask them to adopt the electrical transmission of power. Hitherto it had been generally urged that electricity was only applicable to long distance transmission, and that great economies might be realised in this direction—for instance, in mining work—but he would point out to them that there were just as great and important economies to be realised in short distance transmission, by the concentration of power in one highly efficient generating plant. Economy would only be realised in short distance transmission of power where the working of the machinery was of a very intermittent nature. There were a number of

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economies in electric power work which did not appear to one at first sight, and it was only by the actual comparison of works which had been driven previously by steam, and were now driven electrically, that a true comparison could be made between the two systems. He was now speaking to them chiefly of electric power as applied to old works, but felt sure that in addressing himself to them as a practical body of engineers and shipbuilders, they would at once realise the large amount of coal they were burning per effective H.P. in their works or shipyards. In most of the shipyard machinery it was a universal practice to build small high pressure engines driving the various machines with very large cylinders, so as to allow for the loss of steam between the boilers and the engines. These things had to be provided for in practical working, as it might be found necessary to place the machines at a considerable distance from the boilers. If they took the exact H.P. of work expended in punching or shearing, they would find that these engines were consuming from 90 to 120 lbs. of steam per H.P. per hour. It stood to reason that if they concentrated the work done by all these small high pressure engines in one highly efficient triple expansion engine, using say 20 lbs. of steam per I.H.P. per hour, a great economy would naturally result. This was perfectly feasible and possible with electricity, but by no possibility of mechanical means could the same result be obtained, and if they would go closely into these matters for themselves they would find this to be the case. He had practical experience of works where for very effective H.P. of work delivered, including all losses in the engine, dynamo, cables, switching apparatus, and motors, they were not using more than 25 to 30 lbs. of steam per effective H.P., and this result could with certainty be guaranteed. One of the first considerations they had to look into in the remodelling of existing works was the number of boilers they could dispense with. If they could knock off three or four boilers, and taking the average cost of coal, wages, repairs, etc., on the boilers as between £300 and £400 per annum, a considerable economy would at once be obtained, which would go towards paying for the electrical plant. There

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were, however, many considerations besides the actual coal, one of which was the upkeep, and they had found in actual operation the upkeep on the electric power plants they had at work had been a fractional part of what the upkeep was when the works had been driven by means of separate engines. Amongst some instances in which he had actually applied electric driving to works in this country, was one instance in which they had saved the entire cost of the plant within eleven months. In taking the average of ship-building yards and works throughout the country, they would find that the total capital expenditure would be paid off within three years working of the plant. These results could only be obtained, however, by going into the matter in a thorough manner and making use of a highly efficient engine, efficient generating machinery, and all the necessary economical appliances. It appeared that electricity had not as yet been applied on any very extended scale for power purposes in Scotland; in fact, throughout the whole of England they were considerably behind the Continent and America in applications of electric power. He had only just returned from the North of Italy and Switzerland, and he was much astonished at the large scale in which they were carrying out electric power work in those countries. In one works alone he was in he saw in construction between 25,000 and 30,000 H.P. of electric generators for power purposes. These were mostly on the three phase system in which generators and motors were devoid of commutators and brushes. There were a great many advantages to be derived from this system, but especially in long distance transmission. For large powers the three phase generators were admirably suitable, as they were so exceedingly simple in construction. They had the advantage of being built very economically, and with a high efficiency at very low speeds. He saw some running at speeds as low as 20, 48, 50, and 80 per minute. The system was quite different from anything as yet in this country in practical operation. Most of the small villages and towns in Switzerland were now being provided with electric driving as well as lighting, and small carpenters' and blacksmiths' shops were

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provided with their electric motors. Of course great impetus had been given to electric power in Switzerland owing to the natural facilities due to the abundance of water. Personally he had been connected with but a small portion of what had been done, perhaps some 10,000 H.P. in motor work, but on the Continent it was very different, and everywhere one saw works being driven throughout by means of electricity. Numbers of these works had been driven for the past three or four years exclusively by electricity. They had no other power in the place, so that they had to rely solely on electricity as their motive power. He was remodelling about fourteen works in this country at the present time, and in two or three instances was applying electricity to supersede entirely the old method of driving the works. They had 600 H.P. running since the New Year at the works of the Bedson Wire Co., Middlesbrough. They were putting in another installation of about 400 H.P. at the shipyard of Messrs Furness, Withy, & Co., Hartlepool, about 275 H.P. at the works of Messrs Dorman, Long, & Co., and many other installations. In all these cases they had to rely solely on electricity for driving purposes, and they had no duplicate or other arrangement to fall back upon whatsoever. In nearly all the installations he found that when the novelty and newness of the method had worn off, people looked upon the system with as much confidence as to its reliability as they had done in the old days with old pressure boilers and separate steam engines. They had now in daily practical operation and driven electrically almost every machine that was usually found in engineering works and shipbuilding yards and by constant practice they had been able to overcome almost all the difficulties which presented themselves at first, and which were inherent to every new departure. He hoped that in the few remarks he had had the privilege of making he would have left them something worth thinking over. They might be sure of one thing, and that was that electric driving for engineering works and shipbuilding yards would before long inevitably come to the front. He begged to thank them very much for the kind and attentive way in which they had received the few remarks he had made on the subject.

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Mr WALTER DIXON said he was sorry he was not able to attend the last meeting, but had made the best amends possible by writing the Secretary with reference to the question in hand. He noted, on page 199, that an error had crept in with reference to the abstract from Mr Alexander Siemens' paper to the Federated Institute of Mining Engineers, which should have read thus—"that he has considered and compared the outlay for an electrical plant and for a steam plant, and finds that the capital outlay per brake horse power is 30 per cent. higher in the case of the old steam plant than for the new electrical plant," thus showing that in the case of certain new works electric power can be applied cheaper than in the old method. There had now been sufficient time to speak with some confidence as to the question of depreciation and upkeep. Installations abroad had been running for three or four years under various conditions, and in their own country for somewhat less than this time, and it was safe to say that under these two heads the electric plant did not by any means exceed the usual steam plant, and was probably much less. This being so, with Professor Jamieson's equation before them, the time seemed to have arrived when they should all go in for electric transmission of power. While all the world was bent on economising coal and keeping down working expenses, Professor Jamieson appeared to have lost sight of this factor in his equation. This, however, they were sure was only a slip on his part, and when it was shown, as it had been without any question of doubt, that coal consumption and boiler and engine attendants were considerably reduced when electric transmission was adopted, it was a further reason why this motive power would eventually assert itself over existing methods. In the face of such economies as were being effected, prime cost became quite a secondary matter. They rather felt that they were behind the times, but if in this part of the country they went slowly, they went none the less surely, and could now reap the results and benefit of the experience which was being gained further south. Situated as they were, it seemed very difficult to get it out of their minds that this matter was in the experimental stage, but one only needed to go from twelve to thirty-six hours' journey

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from home to find that what they were only talking about, other nations and peoples had been using for years. Since the last meeting, he had replaced several steam engines by electrical motors driven from existing lighting plants, and the results had been extremely encouraging.

Mr A. W. STEWART said there were one or two points he intended asking Mr Wallace. One was with regard to how the actual power was obtained. Mr Wallace stated that the indicated power was about double the actual power required to do the work, and he would like to ask him how the actual power was obtained, whether it was by brake power, or what. In regard to the table of electrical motor tests, there was a statement about a straightening machine which was replaced by a 3½ horse power motor, and the actual work that this motor was put to do was 5·4 horse power, and he thought that was just asking the motor to do too much. In regard to motor driven punching machines, Clydebank Works had had one in use for some time, and the results had been very satisfactory. As regarded the amount of work done per horse power, based on the amount of metal punched or cut out, it was found that with steel plates, or angles, electric punching gave 4½ cubic inches per E.H.P. per minute; steam punching gave 2¼ cubic inches per I.H.P. per minute; electric drilling gave ·3 cubic inches per E.H.P. per minute. Mr Wallace stated that once electricity was introduced on a large scale, such uses as the boring of stern tubes would suggest themselves, but he thought he was a little behind the time, because actually that work was going on on a big scale at more than one work on the Clyde. In Clydebank they had on one ship no fewer than 15 motors, working from 3 to 5 horse power at one time. This was a time when they were driving from one big engine, and wanted to cut out inefficient engines and boilers, and also to take away the men who might be standing at an engine all day waiting for some one to use it. Then there was a reference made to carbon brushes, but he did not think that would help matters very much. He was sorry that Mr Wallace had been unable to give them prices of a steam system as compared with an electrical system, and also

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that he had not entered more fully into the applications of electric on board ship. Several applications had been discussed at the l meeting, but no mention had been made of the use of electricity heating purposes. He was sure that any one who had sailed mu on board ship, and knew the inconvenience caused by hot and lea steam pipes passing through cabins, etc., in order to convey heat parts further away, would fully appreciate the special advantages be gained by the ideal system of electric heating.

Mr W. CARLILE WALLACE said as it was so very late he wou make his remarks as short as possible. He thanked Profess Jamieson for pointing out the mistake he made with regard t danger to life. He was always very pleased indeed to be corrected in that way, and he must say that he thought the members had handled his paper very leniently; owing to the very short time which he had for preparing it, the subject had not got the thought and care which it deserved. He was rather surprised at the position that Mr Mavor had taken up in saying that he had made too good a case for electricity, but perhaps it was on the principle that he, Mr Mavor, did not want to see a weak foe get too badly handled. Another point which Mr Mavor mentioned was that they could not take the efficiency of the dynamo or generating plant at anything like so high as he did, but he thought that they had certainly a much greater efficiency than using engines on the individual machines. Taking the case of a punch, it was supplied with an engine to punch $1\frac{1}{4}$-inch holes in 1-inch plate. The usual run of work done in shipyards was about $\frac{7}{8}$ holes in $\frac{3}{4}$ plate. Therefore the engine driving the machine was working at about half its power all the time. Now, besides this, all the machines were not working together, so that he believed if they made the generating plant 60 per cent. of the aggregate power of the motors, it would be quite large enough, and under these circumstances the variation in load would be small, and there was very little likelihood of the plant getting too little work to do. Where large power was required they had only to put in two installations—say, in 1000 horse power, a generating plant capable of giving out 600, and another 400 E.H.P.,

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and when the power dropped below 600 E.H.P. they could use the 600 E.H.P. plant, and then the 400 E.H.P. With regard to the remarks of Mr Samuel Mavor, he certainly could not agree with him that triple expansion engines would be less economical than compound ones, especially if the point that he had just mentioned about equalising the power was looked to. He knew instances, under his own knowledge, of marine engines which indicated about 2500 horse power on the trial, and developed in ordinary running from 1400 to 1500 horse power on 1·4 lbs. of coal per I.H.P. per hour; that did not look like a serious falling off of efficiency due to the reduced load. There was another thing that Mr Mavor pointed out, namely, the use of the letter I.H.P. in column 4 of Table II. It should have been E.H.P. As to being able to take the brake horse power of every engine and dynamo, engineers knew that this was a very troublesome and very uncertain process. He was afraid that life was too short to go into such very particular details. He would also thank Mr Dixon for the addition which he made to his paper in his letter to the Secretary; and he certainly would endorse Mr Rowan's remarks, that where ships were fitted with electrical installation the electrical drilling machine would be a very great advantage. He was not prepared to tackle Professor Jamieson's equation. With regard to Mr Stewart's remarks, the actual power was only approximate; it was calculated from the force required to punch the plate, and the distance through which the work was done. With regard to what Mr Stewart said about the boring of stern frames, he did not mean that it had not been already done, because he would imagine that in the case of anybody who had electric plant at all that would be one of the first uses they would put it to. He was only referring to it as one of the obvious uses to which motor driving could be put, and he mentioned the planing of decks in the same way, which was, he knew, an accomplished fact.

The PRESIDENT said that they were very much obliged to Mr Carlile Wallace for his paper, and also to Mr Selby Bigge for his exceedingly interesting address.

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On "The Strength of Ships' Beams.

By Mr W. David Archer.

(SEE PLATES XIII. AND XIV.)

Received 22nd February; held as Read 26th February, 1895.

THERE are very few parts of the structure of a ship for which it is possible to determine, with any approach to accuracy, the forces which act upon them and tend to produce stress and strain. In the case of the deck beams, however, it appears to be possible to determine, for any given condition of loading of the vessel, at least with tolerable accuracy, the principal forces which produce stress. The object of the present paper is to endeavour to determine these forces in the case of vessels of various dimensions, and, having found the forces, to determine the stresses set up by them in beams of the scantlings which are most commonly employed in merchant steamers.

Straining actions may be set up in the beams of vessels by the following sets of forces:—

(1) In all deck beams, by their own weight, and that of the deck plating, planking, etc., resting upon them.

(2) In the beams of weather decks, by masses of water falling upon the decks.

(3) In the case of decks below the weather deck, by the weight of cargo or bunker coals supported by the beams.

(4) By deck machinery, or other articles of equipment.

(5) By the change of momentum of parts of the structure, or of the cargo of the vessel when rolling.

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(6) By the transverse bending of the ship as a whole, especially in the case of docking.

(7) The straining actions set up by the heeling and righting moments in the case of sailing vessels will not be considered here, as not being applicable to the case of steam ships.

The primary object of the beams and pillars is to support the decks and the load of cargo, etc., resting upon them; and it is proposed to consider first the sets of forces No. 1 and No. 3, which, being of the same nature, may be treated together.

Fig. 1, Plate XIII., represents part of the midship section of a vessel, having a moulded breadth of 50 feet, and a height between decks of 7 ft. 11 in., beam to beam. The scantlings of the beams are in accordance with Lloyd's Rules, the upper deck beams being tee bulbs, 11 inches by $\frac{19}{20}$-inch, and the main and lower deck beams 12 inches by $\frac{11}{10}$-inch. The beams are spaced 52 inches from centre to centre, and are plated over with $\frac{9}{20}$-inch deck plating. Each beam is supported by two pillars, instead of the alternate beams having one pillar and three pillars, as suggested by the Rules.

It has been assumed that the upper and lower 'tween deck spaces are filled with a homogeneous cargo of 50 cubic feet to the ton, stowed to the top of the beams. It will be noticed that (except in the case of a self-trimming cargo, such as grain) the cargo on the main deck will not generally be in contact with the upper deck, and that therefore the weight of the upper deck and the load upon it is entirely transmitted to the pillars and framing, and can produce no bending action on the main deck beams. Similarly, the bending action on the lower deck beams is caused entirely by the weight of the cargo on the lower deck and the weight of the lower deck beams and plating. The deck beams are rigidly fixed at the ends and at the heads of the pillars, and, if we consider the main and lower deck beams, each beam is loaded with a uniformly distributed load, consisting of its own weight, that of a strip of deck plating 52 inches wide, and that of a block of cargo of the same width. Under these conditions, and if the beam is straight, the bending

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oment at the four fixed points—*i.e.*, the two ends of the beam and ne heads of the pillars, is given by the formula—

$$M = \frac{WL^2}{12}, \qquad (1)$$

where M is the bending moment in foot tons.
,, W is the weight per foot run in tons.
,, L is the length in feet of the unsupported part of the beam.

The bending moment, midway between the points of support, is one-half that at the fixed points.

In the case of the main and lower deck beams represented in Fig. 1, with a homogeneous cargo of 50 cubic feet per ton, we have the following values—

W = ·741 tons per foot.
L = 16 feet 4 inches.
Whence M = 16·4 foot tons = 197 inch tons.

The stress in a beam of the ordinary bulb tee section is greater at the bottom of the bulb than in the top flange. The greatest stress occurs, of course, at the four fixed points where the bending moment is a maximum, and is given by the formula—

$$p = \frac{my}{I}, \qquad (2)$$

where p is the stress in tons per square inch.
,, m is the bending moment in inch tons.
,, y is the distance in inches of the neutral axis from the bottom of the bulb,
And I is the moment of inertia of the section about the neutral axis, expressed in inches,

Or, combining (1) and (2),

$$p = \frac{WL^2y}{I}. \qquad (3)$$

In the case under consideration,

m = 197 inch tons (as above).
y = 7·2 inches.
I = 206.
Whence p = 6·9 tons per square inch.

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The values of W, L, m, y, I, and the corresponding stress p, are given in Table A (see Plate XIV.) for the lower or main deck beams of vessels varying in breadth from 20 to 50 feet, the depth and thickness of the beams being taken from Table S 4 of Lloyd's Rules.

The stowage of cargo is assumed to be 50 cubic feet per ton throughout.

All beams 42 feet in length and under are assumed to have one pillar at the centre only, while those of 44 feet in length and above are supported by two pillars, according to Lloyd's requirements. The difference in the maximum stress, in the case of the beams supported by one, compared with those supported by two pillars, will be noticed at once.

With regard to the deflection produced in the beams by a uniformly distributed load, such as has been assumed above, the maximum deflection, which, of course, occurs midway between the points of support, is given by the formula—

$$d = \frac{wl^4}{384EI}\ *$$

assuming the beams to be straight before the load comes upon them, where d is the maximum deflection in inches,

„ w is the weight in tons per inch run,

„ E is the modulus of elasticity of the material,

„ l is the length of the unsupported part of the beam in inches,

and I has the same signification as before. Assuming for E the value 28,000,000 lbs., the formula becomes

$$d = \frac{wl^4}{4{,}800{,}000\ I}.$$

The effect of the camber of the beams in modifying stress and deflection has not been gone into, and may probably be neglected for practical purposes.

It will be noticed that the stresses in the last four beams of Table A, numbered 13 to 16 inclusive, are only about one-third of the values which obtain at the other end of the table. If, therefore,

* *Note.*—The above formula applies only to the case of beams which are not strained beyond the elastic limit.

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the forces, which are mainly instrumental in producing stress and strain in ships' beams, are in the nature of a uniformly distributed load, as has been assumed above, it is impossible to escape the conclusion that either the beams at the top of the table are too light, or the last four at the bottom are unnecessarily heavy for their work.

In Table B, the results of the calculations of stress are given for a series of angle bulb beams for vessels having breadths varying from 32 to 42 feet. The scantlings of these beams are as given in Table S 4 of Lloyd's Rules for beams spaced on every frame. The spacing of the beams is in this case exactly half that of the corresponding beams in Table A. Every alternate beam is supported by either one or two pillars, and the intermediate beams by longitudinal girders connecting the heads of the pillars. Table B is extended to show the stress for an $8 \times 3 \times \frac{11}{20}$ bulb angle beam in vessels up to 50 feet beam. The above remark as to the smallness of stress in the beams supported by two pillars, as compared with those supported by one, applies in this case also.

In order to secure uniformity in calculating the moments of inertia of the different sections, each section has been drawn out to scale, the bulb and the thickness of the top flange being proportioned to the thickness of the web, as indicated by Fig. 2, Plate XIII., for the bulb tees, and by Fig. 3 for the bulb angles.

The resistance of the deck plating to bending has been neglected, also the loss of strength due to the two rivet holes connecting the head of each pillar to the beam.

Having determined, for an assumed condition of loading, the stress and strain in the main and lower deck beams, due to the two sets of forces, 1 and 3, it remains to consider briefly whether the other sets of forces, enumerated above, have any sensible effect in increasing or modifying the straining action.

No. 2.—The strains produced in the weather deck beams, by masses of water falling on the decks, can evidently not be dealt with by calculation, but if the pillars of the several decks are over

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one another, no strains are transmitted to the main or lower deck beams. Similar remarks apply to section No. 4.

No. 5.—When a vessel is rolling, and comes to the end of the roll, the direction of motion of the cargo as well as of the structure itself is reversed by the action of the righting moment due to the inclination of the ship. The force necessary to produce this change of momentum is transmitted to the cargo by the structure of the ship, and the reaction tends to produce a bending action in the frames and shell plating of the topsides and a tensile stress in the beams.

Suppose the vessel represented by Fig. 1 to be 50 feet in breadth, and 35 feet moulded depth, and the centre of gravity of the ship and cargo to be 24 feet above the top of the keel. Assume the period of a double roll to be 10 seconds, and the maximum angle of roll 40 degrees, which is an exceptionally heavy roll for a merchant steamer,

The maximum angular acceleration is then ·25 per second (circular measure).

A point midway between the main and upper decks is about 8 feet above the centre of gravity, and its maximum linear acceleration (which is a measure of the force producing it) is therefore $8 \times \cdot 25 = 2$ feet per second, or $\frac{1}{16}$ that of gravity.

The weight of the cargo per beam space being about 34 tons, it follows that the maximum tensile force which is divided between one upper and one main deck beam will be only 2·1 tons, equivalent to a stress of about one-tenth of a ton per square inch; a figure which is quite insignificant compared with the values of column 10, Table A.

No. 6.—The straining actions caused by the transverse bending of the ship as a whole, when either afloat or in dock, are of a very complex character. When the ship is afloat the weight of the topsides and decks, and the cargo upon them, is transmitted downwards by the pillars and frames and is balanced by the upward pressure of

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the water distributed uniformly along the ship's bottom. When, however, the ship is in dock, before the bilge shores are in place, the upward supporting force is entirely concentrated at the keel, and it is therefore reasonable to suppose that the strains on the beams and the rest of the structure, due to transverse bending, will be greater when in dock than when afloat.

This subject of transverse bending when in dock has been investigated by Mr T. C. Read and the late Professor Jenkins in their paper on the "Transverse Strains of Iron Merchant Vessels," read before the Institution of Naval Architects in 1882. In the engine and boiler spaces, where the transverse strains due to docking are evidently greater than towards the ends of a ship, the beams are necessarily to a certain extent dispensed with, and their place is taken as regards the resistance to transverse bending by web frames or partial bulkheads. The deep floors and inner bottoms of vessels with ballast tanks also help to relieve the beams of the bending action when being docked. On the whole it appears probable that the stresses induced in the beams by transverse bending while docking will not exceed the stresses brought upon them by the weight of homogeneous cargoes of such densities as are in practice carried upon the beams. Such being the case, it appears reasonable to determine the scantling of a ship's beam of given unsupported length by the consideration of its ability to carry the weight of a homogeneous cargo of the maximum density likely to be carried on the beam.

In this connection the first point to be determined is the greatest admissable stress. Referring to Table A, the stresses and deflections indicated under the assumed conditions of loading, amounting in the case of section No. 2 to a stress of 21·8 tons per square inch, and a deflection of about ¼-inch in a length of 10 feet 9 inches, could not be borne without a failure of the material.

In such small vessels, when intended for carrying deadweight cargoes, lower deck beams are usually not fitted at all, and when

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used as passenger vessels the strains are, of course, nothing like so severe as those indicated.

In constructing Tables C and D, giving proposed scantlings for the beams of the midship portions of the second, third, or fourth decks of steamers, the following assumptions have been made:—

1. That the calculated stress should not exceed 14 tons per square inch.

2. That the scantlings of the beams given in Table A, for vessels of 20 feet to 42 feet breadth, and supported by one row of pillars, are just sufficient for the work they have to do.

By the formula (3) giving the stress in terms of W, the weight per foot run, and L, the unsupported length of beam, the density of cargo appropriate to a stress of 14 tons per square inch was found for the series of beams 1 to 12 in Table A, and the results have been plotted in the form of a curve, as shown by Fig. 4, Plate XIII., where the abscissæ represent breadth of ship and the ordinates density of cargo in cubic feet per ton. The curve was produced in a fair line beyond the last ordinate BB, and at CC, corresponding to 54 feet beam, it is parallel to the base line, the value of the ordinate being 45 cubic feet per ton. At AA, corresponding to 20 feet beam, the value of the ordinate is 85 cubic feet per ton. The curve, A B C, has been used in getting out the Tables C and D, the scantlings given in those tables being such as are required to keep the calculated stress below 14 tons per square inch when the beams are loaded with a homogeneous cargo of the density given by the curve. Table C is for beams spaced on alternate frames, and Table D for beams on every frame. The scantlings of the beams, supported by one row of pillars for vessels ranging from 20 to 42 feet in breadth, are of course practically the same in Table C as in Table A, but in the case of beams supported by two rows of pillars a considerable reduction in the scantlings will be noticed, and the table has been extended to indicate the scantlings on the same basis for beams supported by three rows of pillars and for vessels up to 68 feet beam.

In order to give some idea of the approximate saving in the weight of hull of a vessel due to a reduction in the scantlings

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of the beams, such as is indicated by Table C, compared with Table A, the following figures for a passenger and cargo steamer, 420 feet × 51 feet 9 inches × 35 feet 5 inches, classed 100A1, may be of interest:—

Scantling of main and lower deck beams—

By Table A, 12 inches × $6\frac{1}{2}$ inches × $\frac{11}{20}$.

„ C, 10 „ × 6 „ × $\frac{10}{20}$.

Reduction in weight of beams per foot run, 21 per cent.

Assuming the upper deck and the orlop deck beams to be reduced in proportion, the saving in the weight of upper, main, lower, and orlop deck beams would be 21 per cent. of 190 tons, or about 40 tons.

In conclusion it is submitted:—

1st.—That in modern steam vessels of large size the beams are relieved to a large extent of the straining action due to the transverse bending of the ship as a whole by the introduction of deep web frames, not only in the machinery spaces, but also in the cargo holds; and also by deep floors, inner bottoms, and closely spaced transverse bulkheads; and that it is therefore unnecessary to employ beams of such heavy scantlings as may have been necessary in the case of vessels built before the adoption of such improved methods of construction.

2nd.—That in determining the scantlings of beams for a given breadth of ship, sufficient regard is not usually paid to the number of rows of pillars which may be adopted.

The Tables C and D make no claim to completeness, in particular no scantlings are given in Table D for channel bar beams, which are widely used in preference to angle bulbs in vessels of large size.

It is hoped, however, that the figures given in the tables, and the method adopted in obtaining them, may be of some use to shipbuilders and naval architects in their endeavour to get rid of some of the unnecessary material which we still put into the hull of our ships, and which is a constant bar to progress in the direction of higher speeds and also of greater propulsive economy.

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The discussion of this paper took place on 30th April, 1895.

Mr F. P. PURVIS thought that the thanks of the Institution were due to Mr Archer for his paper. So far as he had followed the paper, it had to some extent been anticipated by the work done in the British Corporation, although Mr Archer's results seemed to show a more sanguine expectation than the Corporation took. Perhaps Mr Archer might have done more justice to the subject if he had also dealt with the nature of the connections of pillars to beams, with a view to securing thorough efficiency in this respect.

Mr CLEGHORN said that Mr Archer tabulated, on page 213, a series of seven different sets of forces by which straining action might be set up in beams; and he thought that another set, which had been omitted, might have been added. This eighth force was that due to the inertia of the cargo, deck and beams, when the ship was heaving. In a storm, waves 350 feet long, having height of 32 feet or more, and a period of about eight seconds, might be encountered. A ship might never experience such a sea broadside on, but it would be safe that this condition should be recognised. Under these conditions, and assuming that the vertical motion of the vessel was simple harmonic, the additional force on the deck beams, when the ship was in the hollow of the wave, would be about 39 per cent. of the weight of the cargo, deck and beams—that was to say, for every ton of cargo, deck and beams, an addition of about ·3 to ·4 ton had to be made. So far as he saw, that force had not been taken into consideration. Its omission did not alter greatly the relative value of the results given by Mr Archer, but he would like to ask Mr Archer if he regarded such a force as negligeable, and if not, then what ratio the actual increase of load might bear to that deduced from the assumption that the vertical motion of the vessel was simple harmonic. He believed that the class of stress, to which he had referred, was of greater importance than set (5) mentioned on p. 213.

Mr ARCHER, in reply, thanked the members who had spoken on the paper, and remarked that he wished to make a correction with regard to the formula for deflection, given on page 216, and the deflections given in columns 11 and 12 of Table A. The formula

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for deflection, on page 216, was based on the theory of elastic beams, and was not true for beams strained beyond the elastic limit. The stresses in column 10 of Table A were in some cases over 20 tons per square inch with the assumed load, and, therefore, the figures given for the deflection were not correct under the assumed conditions. With regard to the remarks made by Mr Purvis, he did not, of course, know what method the British Corporation had adopted in getting out the scantlings of beams, but he had compared the scantlings given in the tables of the British Corporation with the scantlings at which he had arrived, and had found that the Corporation scantlings, especially in the case of broad ships with two or more rows of pillars, were considerably heavier than the scantlings of Tables C and D. With regard to the spacing of pillars, one of the principal points which he wished to make, was that sufficient attention was not as a rule paid to the spacing of the pillars when determining the scantlings of beams. With regard to the fastenings at heads and heels of pillars, that was a most important point, but was a little outside the scope of the paper. With reference to Mr Cleghorn's remarks, he understood him to mean that the ship in passing over a wave had a vertical motion, which caused a variation in the virtual weight of the cargo. This was perfectly true, and no doubt produced a slight increase in the straining action of the beams. This action, he must confess, he had omitted to take into account, but in such a method as that he had adopted for determining the approximate scantlings for beams, which was of necessity to some extent empirical, it was not, he thought, necessary or useful to introduce complications which would not add to the value of the results arrived at. He thanked the members again for the way they had received his paper.

On the motion of the President, a vote of thanks was given to Mr Archer for his interesting paper.

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The late Mr Lindsay Burnet.

At the meeting held on 26th March, 1895, Mr George Russell, Vice-President, in the Chair,

The CHAIRMAN said—I should like in one word to make reference to a Member of Council of the Institution who has died within the past week. I refer to Mr Lindsay Burnet, whom a great many present here to-night would know. At our last meeting he could not be present, but he sent some notes for the discussion on one of the papers, showing the great interest he took in the Institution, even when he was in very poor health. He has died in the prime of life—being only thirty-nine. Those who knew him well, knew how loveable he was. He was an able engineer and a good man, and I beg to express on behalf of the Council and Institution our deep regret at his early death.

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On the "Extension of the Loch Katrine Water Works.

By Mr JAMES M. GALE, M.Inst.C.E.

(SEE PLATES XV., XVI., XVII., XVIII., XIX., AND XX.)

Received 18th February; Read 26th March, 1895.

IN the last paper which I had the honour to read before this Institution, in March, 1883,* I brought up the history and description of the Loch Katrine Water Works to the time when the whole works were completed, according to the original design, for bringing 50 million gallons of water per day from Loch Katrine to Glasgow, and for its distribution in the city. These works have been fully described to the Institution in my previous papers of the Session of 1863-64,† of March, 1869,‡ and in the paper of 1883 first above referred to.

The necessity for extending the works has arisen earlier than was anticipated, and has been brought about by two causes—first, the rapid increase of the population supplied, and the growth in the demand for water for trade purposes, and—second, imperfections in the formulæ used in calculating the flow in the aqueduct.

This communication will be confined to a consideration of these causes; to a statement of the principles followed in designing the new works; and to a short description of the works themselves, so

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* Transactions of the Institution of Engineers and Shipbuilders in Scotland, Vol. XXVI., page 151, March, 1883.

† Do. do. Vol. VII., page 21, November, 1863.

‡ Do. do. Vol. XII., page 125, March, 1869.

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far as they have been executed. The subject will be treated under the following heads :—

1. Increase in the population.
2. The discharge of the old aqueduct.
3. The Act of 1885.
4. The line of the new aqueduct.
5. Dimensions of the new aqueduct.
6. Construction of the new aqueduct.
7. The syphon pipes.
8. New service reservoir.
9. New mains to the city
10. Works at Loch Katrine.
11. Loch Arklet.
12. Estimates and cost of works.
13. Purchase of feuing rights at lochs.

1. INCREASE IN THE POPULATION SUPPLIED.

In the year 1852 the population of Glasgow and suburbs was 360,000, and in 1853, when the Loch Katrine Water Works were being designed, it was observed from the census returns that it had been increasing during the previous twenty years, or from 1831 to 1851, at the nearly uniform rate of 7000 per annum. It was thought that this increment might increase to 9000 per annum, and that the average increase up to the end of the century might safely be taken at 8000 per annum. The quantity of water supplied per head in 1852 was considered excessive, and amounted to about 40 gallons per day, and if this had continued to be sufficient, and if the population had increased in the anticipated ratio, the daily supply required at the end of fifty years, or in the year 1900, would have been 30 million gallons per day. But the population increased in a much more rapid ratio, and the quantity of water consumed per head rose from 40 to 50 gallons per day, with the result that 30 million gallons, instead of lasting the city half a century, were required in less than half that time, or by the year 1872. The population of the whole district, and the quantity of water supplied per day and

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per head, are given at intervals of five years in the table below. Between 1852 and 1861 the increase in the population was 8500 per annum, and nearly followed the anticipated ratio, but for the five years ending with 1866 it was at the rate of nearly 13,000 per annum, and for the ten years ending with 1876 it averaged over 19,000 per annum. In 1878 the failure of the City of Glasgow Bank took place, and for the five years ending with 1881 the increase was at the rate of 6000 a year only; but since 1881 the increase has averaged 12,460 per annum.

Table showing the Population supplied with Water, and the Consumption per head per day, at intervals of five years.

Year at April.	Population supplied with water.	Average increase of population each year.	Average quantity of water supplied per day during whole year.	Consumption per head per day.			
				Meter supplies.	Other trade supplies.	Domestic, including Municipal purposes.	Total.
			Gallons.	Galls.	Galls.	Galls.	Galls.
1852	360,000		14,000,000	3·25		35·65	38·90
1861	436,901	8,545	18,264,864	2·87	2·95	35·99	41·81
1866	501,200	12,856	23,737,908	4·57	2·95	39·84	47·36
1871	595,224	18,805	29,595,657	5·96	3·60	40·16	49·72
1876	694,548	19,865	31,710,844	7·03	4·76	33·86	45·65
1881	724,702	6,031	37,329,237	9·43	5·29	36·79	51·51
1886	796,965	14,452	40,813,815	9·74	5·48	35·99	51·21
1891	845,564	9,720	41,920,698	11·38	6·06	32·13	49·57
1894	886,798	13,745	45,089,830	12·00	6·41	32·43	50·84

The increase in the quantity of water consumed per head is entirely due to an extension of its use for trade and manufacturing purposes. The quantity so used in 1852 was 3¼ gallons per head per day, and this has steadily increased till it now amounts to 17 gallons per head. In recent years the number of public urinals, watering troughs for cattle, drinking fountains, ornamental fountains in the various parks, and public bathing establishments have largely increased. The introduction of baths into the modern houses, erected for the well-to-do working classes, the compulsory fitting up

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of water closets in the smaller class of houses, the supplying of all domestic water direct from the mains, and the general introduction of hot water throughout the better class of houses, all tend to a more lavish use of the water. The fact that while trade supplies have largely increased, the consumption under the head of domestic and municipal purposes has remained nearly constant, shows that the efforts to prevent unnecessary waste, and to introduce a better class of fittings into the houses generally, have been attended with some measure of success.

2. THE DISCHARGE OF THE OLD AQUEDUCT.

The other cause referred to as having hastened the extension of the works, is the disappointment that has been experienced in the quantity of water the aqueduct can carry from Loch Katrine. It is well enough known by those who have had their attention directed to hydrodynamics, that all the formulæ in use at the date of the designing of these works were based upon two widely different classes of observations—one being upon smooth pipes and troughs of small dimensions, with rapid falls, and the other upon channels and rivers of large sectional area, with small falls. The resistance in these two classes of channels was found to be nearly alike, and the true causes of retardation were not discovered. It was not known till M. Darcy published his observations on the flow of water in pipes in 1857,* that the relative roughness of the inside surface of pipes had any influence upon their discharge, in fact it was confidently believed, and strongly asserted, that the condition of the surface of the pipe had no effect upon the discharge.† All this was dissipated by Darcy's experiments, who also discovered that the larger the diameter of the pipe, the less was the resistance; and conceiving that similar results would be obtained in the case of open channels, he, in conjunction with M. Bazin, entered upon this

* "Recherches experimentales Relation au Mouvement de l'Eau dans les Tuyaux," par Henry Darcy, 1857.

† See Minutes of Proceedings of the Institution of Civil Engineers, Vol. XIV., page 293, *et seq.*

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more extended question, and their observations, published in 1865,* fully confirmed their anticipations. Other observers continued the investigation, and reliable experiments soon accumulated in sufficient numbers to enable MM. Ganguillet and Kutter, of Berne, in 1869 and 1870, to frame a general formula, applicable to all dimensions and conditions of channels, which was made known in England by a translation in 1876.†

The general expression for the flow of water in channels is given by the equation

$$v = c\sqrt{rs}, \quad - \quad - \quad - \quad (1)$$

in which v is the mean velocity of the stream per second; r the hydraulic mean depth, or the area of the cross section of the stream, divided by its wetted perimeter; s the sine of the inclination of the surface of the stream, or the fall in any given length, divided by that length, and c a co-efficient to be determined by experiment. Dubuat, in 1786, found that the value of c depended upon several elements, but all the other writers upon this subject, down to the time of Darcy, assert it to be dependent upon the velocity only, irrespective of the size, shape, inclination, and condition of the channel. Darcy and Bazin found that the area of the section had to be allowed for, and that the roughness of the perimeter had a controlling influence, and Ganguillet and Kutter found that it also depended upon the slope of the stream, and, as regards the influence of the roughness of the channel, they found that for small channels, differences of roughness have a great influence on the discharge; that for very large channels, differences of roughness have very little influence; and, therefore, that for indefinitely large channels, the influence of different degress of roughness must be assumed to vanish.

A formula, to give affect to all these varying conditions, could not of course be a simple one. As elaborated by Ganguillet and Kutter,‡ it is as follows—

* Recherches Hydrauliques, par H. Darcy et H. Bazin, Paris, 1865.

† Kutter's Hydraulic Tables—translated by L. D'A. Jackson, 1876.

‡ "A General Formula for the Uniform Flow of Water in Rivers and other Channels," by E. Ganguillet and W. R. Kutter, 1889.

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$$c = \frac{a + \frac{l}{n} + \frac{m}{s}}{1 + \left(a + \frac{m}{s}\right)\frac{n}{\sqrt{r}}} \quad - \quad - \quad (2)$$

in which a, l, and m are constants, and n the variable co-efficient depending upon the roughness of the surface. The values found for a, l, and m, were 41·6, 1·811, and 0·00281 respectively, and the formula for the velocity becomes

$$v = \left\{ \frac{\frac{1{\cdot}811}{n} + 41{\cdot}6 + \frac{0{\cdot}00281}{s}}{1 + \left(41{\cdot}6 + \frac{0{\cdot}00281}{s}\right)\frac{n}{\sqrt{r}}} \right\} \sqrt{rs} \quad - \quad - \quad (3)$$

and this is now generally called Kutter's equation.

Attention was early directed to the irregularities in the depth of the water in the aqueduct, but it was not till 1880 that an attempt was made to deduce the values of n, in Kutter's formula, for the various portions of it. The discharge is measured at its southerly end, as it flows into the Mugdock reservoir, over cast-iron plates, brought to a thin edge, 40 feet wide, in four bays, each 10 feet wide. To determine the proper co-efficient for this weir, velocity observations were made in a part of the aqueduct which was quite straight, and of uniform area and section, and the value of m in the equation

$$\text{Q per sec.} = \tfrac{2}{3}\, m\, \sqrt{2gh}\, \text{A} \quad - \quad - \quad (4)$$

was found to be 0·633, from which we have

$$\text{Q per min.} = 203\, \sqrt{h^3}\, b \quad - \quad - \quad (5)$$

A being the area of the water section, measured from still water behind the weir, and b the breadth of the weir. The calculations of the discharge of the aqueduct about to be submitted, were made from this formula, at a time when the flow was at the rate of 75·48 cubic feet per second, or 40,759,200 gallons per day, and they proceed upon the assumption that the aqueduct is of perfect shape, no allowance being made for inequalities in the rock cuttings. The area of the water section, and the level of the surface of the water,

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was obtained with accuracy at 23 points, thus dividing the aqueduct into 22 sections.

The section of greatest resistance was found to be the Mugdock tunnel, 1½ miles long, in which the value of c in equation (1) was 56·89. Then follows the Loch Katrine tunnel, 1½ miles long, and about half-a-mile of the aqueduct south of Drumore tunnel, with about 11 per cent. of the length lined, with values of c of 67·8 and 67·72 respectively. Third in order follows 5¼ miles at the northerly end of the aqueduct, where the lining averages 21½ per cent. of the length, in which the value of c varies from 70·9 to 73·75, and averages 72. In these portions of the aqueduct, the bottom consists of broken stone. The southerly sections of the aqueduct are in great part lined, some of them are wholly lined, and in 8½ miles the values of c averages 90·8.

The values of c, for a channel similar to this aqueduct, calculated from the various formulæ proposed prior to Darcy's investigation, are as follows:—Dubuat, 84·88; Prony, 91·54; Eytilwein, 89·29; Weisbach, 92·44; Beardmore, 94·2. These values approximate to those found on the Loch Katrine aqueduct, where it is lined with pick dressed masonry, but they are wholly inapplicable to the rock cuttings.

The values found for n, in Kutter's formula equation (3), were, for the Mugdock tunnel, 0·0292; for the Loch Katrine tunnel, and the tunnel south of Drumore, 0·025; and for the lined parts of the aqueduct, 0·0184, where c was 90·8.

The maximum discharge of the aqueduct was found to be 42 million gallons per day, and to pass this quantity, the sides of some of the cast-iron trough bridges, in the northerly part of the aqueduct, had to be raised. The first part to give trouble was the Drumore tunnel, and this was met by adding 12 inches to the sides of the Castle Burn bridge, which lies immediately to the north. Afterwards, as the quantity of water required increased, the resistance set up by the Mugdock tunnel, dammed the water back in the Blane and Killearn sections, but the bridges on this section could not be adapted to pass more water with safety.

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The possibility of widening the tunnels, or of lining them so as to reduce friction, was frequently discussed, but on account of the short time it was possible to dispense with the flow from the loch, and the extensive nature of the operations, the proposal was found to be impracticable.

In 1883, the quantity of water required by the city averaged 38 million gallons per day, of which 4 million gallons per day were furnished by the Gorbals works, leaving 34 million gallons to be drawn from Loch Katrine, or 8 millions short of the full discharge of the aqueduct. From the introduction of the Loch Katrine water in 1861 to the year 1883, the quantity of water required increased, on an average, about one million gallons per day each year, so that if the same rate of increase continued, it was apparent that the balance of 8 millions would be exhausted in eight years. To admit of the periodical painting of the iron bridges, and the making of repairs inside the aqueduct, stoppages in the flow, for a few days at a time, have to be made at intervals of two or three months, and these lessened the available average flow by about 10 per cent., so that the surplus water was reduced to four years' supply. This appeared a short enough time for obtaining an Act of Parliament, and for executing new works—and accordingly, in the session 1884-85, an Act for the extension of the works was applied for.

3. THE ACT OF 1885.

The original Act authorised the withdrawing of 50 million gallons of water per day from Loch Katrine, and as the aqueduct could only take 42 millions, a new aqueduct was the most pressing piece of work required; but as this was also the most expensive part of a new scheme, it was resolved to apply for power to duplicate the whole works, and to design them for an ultimate supply to the city of 100 million gallons per day. The source from which the additional water was to be drawn did not admit of much discussion. The power to draw 50 million gallons per day from Loch Katrine did not exhaust the resources of that loch, which was selected forty years ago after a lengthened and minute inquiry into all the

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available sources which had been suggested during a previous period of twenty years over which the discussion had been protracted, and the selection has been amply justified by the results. From Loch Katrine and the adjoining lochs large quantities of water can be obtained without injury to any interest. The hills are all of the same geological character, and they all yield water of equal purity. Loch Katrine too is the lowest in level of the whole series of lochs, including Loch Lubnaig, so that the additional water can be all discharged into it, while there is no nearer point from which the water can be drawn to the city than the starting point of the old aqueduct; but before passing into other districts it was thought to be proper to make the most of the sources already possessed by the city and of those in the immediate vicinity, which naturally flow into the valley of the Clyde. (See Fig. 1, Plate XV.)

The works asked by the Act of 1885 consisted of—1st, a new aqueduct following nearly the line of the old aqueduct, and additional lines of mains from the service reservoir to the city; 2nd, the raising of the present high water level of Loch Katrine 5 feet to obtain additional storage, by which means the quantity of water that can be drawn from it will be increased from 50 to 65 million gallons per day; and, 3rd, the converting of Loch Arklet, which flows into Loch Lomond, into a reservoir by raising it 25 feet in level, by which a further supply of 10 million gallons per day will be got. This 25 million gallons, in addition to the 8 million gallons of unexhausted powers over Loch Katrine, would, it was thought, provide for all probable demands for 40 years, and it was not considered prudent to load the Bill with any interference with the River Leny, from which the additional 25 million gallons, to make up the total of 100 millions, is intended to be drawn.

The works embraced in the Act presented the unusual feature that their execution could be spread over a lengthened period of time. The portions of the aqueduct which present the greatest obstruction to the flow could be duplicated in any desired order so that the whole 50 million gallons which can be drawn from the loch as it stands may be made available. The storage at the lochs

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could be increased in two instalments—1st, by the raising of Loch Katrine; and, 2nd, by the embanking of Loch Arklet, and the laying of the pipes across the valleys on the line of the aqueduct and between the service reservoir and the town, could follow. It was seen that these works could be carried out from time to time as the demand for water arose—if that demand was not so great in the future as in the past, the works could be spread over a proportionately greater number of years, and in this way it was expected that the whole might be carried out without adding anything to the rates.

To carry this proposal into effect it was necessary to ask special powers from Parliament, and these were obtained. The whole land required for the aqueduct and pipes had to be acquired within seven years from the passing of the Act, but the execution of the works may be spread over any number of years. The agreed upon price for the privilege of raising Loch Katrine 5 feet, and Loch Arklet 25 feet, had to be paid upon the passing of the Act, but the additional land to be covered by water and occupied by works is not required to be purchased till the works themselves are needed, and these may be indefinitely postponed. These powers could not have been got without the consent of the various owners of the land affected, and in carrying out the negotiations the Commissioners were met by them in the most friendly manner. Of course they had to be paid for their interest in the lochs, and they will have to be paid for their land when it is required for works, but in the meantime a large saving of outlay has been secured.

The mill owners on the River Teith, when consulted as to their interests as regards compensation water, expressed themselves as quite satisfied with the provisions under the Act of 1855, whereby they were secured a daily flow of 40½ million gallons per day out of Loch Vennachar, and the mill owners on the River Leven, who were affected by the abstraction of water from Loch Arklet, accepted 9 inches of rainfall over the area of the water shed intercepted, or a uniform flow of 1,737,000 gallons per day, as a sufficient compensation.

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The interests of the owners of salmon fisheries on the River Teith, and of the Commissioners of the Forth Navigation, presented some difficulty at first; but as regards the fishery owners they were ultimately satisfied by a small additional quantity of compensation water to be discharged from Loch Vennachar during certain seasons of the year, and as regards both, by an increase of the annual sums paid in the name of damages under the original Act, all being postponed till more than 50 million gallons per day are drawn from Loch Katrine; and thus, this Act, involving an ultimate expenditure of one million sterling, and affecting several important water rights, passed both Houses of Parliament as an unopposed measure, with the exception of a trifling local objection.

4. THE LINE OF THE NEW AQUEDUCT.

It was at first intended that the new aqueduct should follow pretty closely the line of the old one, and in designing the works, the best kind of bridge for carrying the water channel across the ravines on the line, especially those in the vicinity of Coulegarton and the Duchray Water, had again to be considered. There are five of these bridges, varying in length, from 372 feet to 996 feet, and of a total length of 2,907 feet. They consist partly of cast-iron troughs, supported upon rubble masonry, and partly of rectangular wrought-iron tubes carried upon piers 50 feet apart.* Variations in temperature expose them to severe strains, and to prevent corrosion they have to be repainted every three years, which necessitates the shutting off of the water at the Loch, thus diminishing the efficiency of the whole aqueduct. These bridges have always been looked upon as the weakest part of the aqueduct, and it appears certain that they will have to be renewed in course of time. It was accordingly resolved not to repeat this feature in the new works, and drawings were made for a series of arches carrying either a strong cast-iron trough, jointed so as to admit of a small amount of movement, or a built channel for the water;

* For a description and drawings of these bridges, see Transactions of the Institution of Engineers and Shipbuilders in Scotland, Vol. VII., page 53.

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but as the district does not furnish good building stone the principal materials would have had to be brought from a considerable distance, at great expense, or, otherwise, concrete would have had to be used. The experience of using monolithic structures of concrete for conveying water was not encouraging. Concrete arches were largely used in the Vanne Aqueduct, constructed between 1867 and 1876, which brings to Paris a portion of its water supply (Fig. 3, Plate XVIII.), and M. Belgrand, the engineer of the works, says*—"Whatever may be the type and the materials employed, long series of arches are always the least substantial parts of an aqueduct. The portions constructed under ground and receiving water that varies very little in temperature are preserved in consequence in a perfect state, but it is not so with the parts constructed above ground. In the case of the concrete arches, particularly when they are of great extent, the variations of temperature produce most troublesome effects. In winter they contract, which causes transverse rents, and in summer, during the hot time of the day, the arches supporting the aqueduct rise upwards, and form longitudinal radiated fissures." With the object of remedying this state of things, he covered up the lower arches with earth, planted ivy in the case of those of greater height, covered the top with mattresses of turf, and planted trees as a further protection. But these preventive means were not always sufficient, and he had recourse to sheets of lead to close the fissures, which were causing leakages that could not be tolerated, and, ultimately, he was led to try the making of artificial joints by cutting the arch of the aqueduct perpendicularly to its axis at frequent intervals.

A similar result was experienced in the case of the aqueduct bridge of Mont-Saint-Pont, on the line of the Haine aqueduct, which supplies Brussels with a portion of its water. The bridge is 875 feet long, is entirely of brickwork, and the water channel is cemented inside (Fig. 4, Plate XIX.). Shortly after its completion,

* "Les Travaux Souterrains de Paris," tome IV.; "Les Eaux Nouvelles," par M. Belgrand, Paris, 1882, page 283.

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leakages began to appear, and continued to increase, and in winter a mass of ice became suspended from the structure. The cement lining was repaired and renewed from time to time, but without effect. M. Verstraeten, the engineer in charge, says:—"The cracks and the swellings declared themselves in a more and more threatening manner, and it was necessary to have a thorough remedy. The bridge had cost nearly £8000, without counting the considerable annual repairs. A cast-iron syphon pipe, 23·62 inches diameter, was laid in the ground alongside of the bridge, at a cost of only £800, and this has relieved us of all anxiety. It is certain that the alternations of cold and heat of the atmosphere, as well as the constant inequality of temperature of the interior and exterior, were the principal causes of the injuries observed, but it is probable that strong gusts of wind bore also a part."*

The masonry bridges on the line of the old aqueduct have given much trouble from the same cause. On the occurrence of severe frost the top courses of the masonry are lifted from their beds, causing extensive leakages, which have to be made good by cementing inside. This, however, has been permanently cured as regards five of the bridges north of the Endrick Valley (Fig. 5, Plate XIX.) by lining them inside with cast-iron plates, and those south of the Endrick (Fig. 6, Plate XIX.) will probably have to be treated in the same way.

From some of the writings which have been handed down to us it does not appear that the Romans, in the magnificent structures across the Campagna, which have been eulogised and admired in all ages, were more successful in resisting the destructive effects of changes of temperature than in the modern cases I have cited, in fact it would seem that they were always in a chronic state of disrepair. Even under the first Emperors the use of some of them was totally suspended for several years at a time, and the necessary repairs amounted in some cases to a total reconstruction. While the arches and piers of these structures were of the most massive

* "Les Eaux Anciennes et les Eaux Actuelles de Bruxelles," par Theodore Verstraeten. Bruxelles, 1884.

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kind, the water channels themselves had little protection, and were directly exposed to the action of the sun and atmosphere.

As regards the new aqueduct, however, a simple way of meeting the difficulty presented itself, and this was to divert the line so as to avoid the broken and irregular ground in the vicinity of the Duchray Water, and to cross the valley at a higher point than that at which the old aqueduct crosses, and thus not only save the construction of bridges, but also the necessity for an inverted syphon. This diversion extended over a length of 6 miles 23 chains, and shortens the length of the aqueduct by 31½ chains, but it involved a tunnel 2½ miles long.

As the new aqueduct could not be safely constructed at a less distance from the old one than 20 or 25 yards farther into the hill sides, the extent of tunnelling was thereby largely increased; but, from the experience with the old aqueduct, it appeared that this would ultimately be the least expensive mode of construction, while there could be no question that the channel would be thereby more permanent and enduring. It was therefore resolved that, instead of following the old line, the new aqueduct should consist throughout of a series of tunnels, and that the water channel be kept as far as possible under ground and removed from the action of the atmosphere. (See Fig. 2, Plates XVI., XVII., and XVIII.) The forming of long tunnels has in recent years been much simplified, and the time required for their execution much shortened, by the use of compressed air for driving the drills for boring the short holes, and by the discovery of more powerful explosives than gunpowder. The length of each tunnel was in most cases determined by the configuration of the ground, but, where there was any choice, they were restricted to one mile in length so as to facilitate the removal of the soil during construction.

To carry out the intention of constructing the new aqueduct in sections it was necessary to form junctions between the aqueducts at the ends of each section. There are seven points of connection, and they will be described hereafter. After the whole aqueduct is completed these connections will be used for isolating any section of either aqueduct when repairs are required.

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5. DIMENSIONS OF THE NEW AQUEDUCT.

As has been already stated, the extension of the works was designed with the object of ultimately maintaining a supply of 100 million gallons of water per day to the city, and to ensure that this would be the average discharge of the two aqueducts, their maxim discharge was fixed at 10 per cent. greater, or 110 million gallons per day. Of this quantity the old aqueduct is calculated upon as producing 40 millions, leaving 70 million gallons to be contributed by the new aqueduct.

The diversions of the line above referred to reduced the total length of the aqueduct from 25 miles, 29 chains, 13½ yards, which is the length of the old aqueduct, to 23 miles, 48 chains, 5½ yards, a saving of 1 mile, 61 chains, 8 yards of distance. The total available fall in the surface of the water, reckoning from the lowest level to which the water can be drawn in Loch Katrine, to the level of the water in the gauge basins at Mugdock, is 38·58 feet. The shortening of the length, and the saving of head by being able to dispense with syphon pipes at the crossing of the Duchray Valley, admitted of a slightly greater inclination being given to the water than in the case of the old aqueduct. The fall of the tunnelled portions of the new aqueduct has been fixed at 1 in 5500, and of the syphon pipes of 1 in 960.

A consideration of the results obtained from the old aqueduct showed that the value of the co-efficient n in Kutter's formula, equation (3), could be safely taken at 0·025 where the tunnels were in rock and not lined. The higher value found in the case of the Mugdock tunnel, viz., 0·0292, was rejected, as this tunnel is exceptionally rough and out of shape.*

The section adopted for the rock cuttings is shown by Fig. 7, Plate XIX. The excavation is 11 feet wide at the bottom, 12 feet wide at a height of 6 feet above the bottom, and 9 feet high, the top being a segment of a circle with a rise of 3 feet. The bottom has a

* This tunnel has recently been dressed up inside, additional lining put in, and the bottom laid with concrete, at a cost of £8000.

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concrete invert with a versed sine of 6 inches. With the water flowing 7 feet deep we have the following data :—

Area of water section = 78·28 square feet = A.
Wetted perimeter = 24·88 lineal feet = p.
Hydraulic mean depth = $\frac{A}{p} = \frac{78·28}{24·88} = 3·1057 = r$.
Inclination = $\frac{h}{l} = \frac{1}{5500} = 0·000,181,8 = s$.

With n in Kutter's formula = 0·025 the value of c becomes 71·57, and the velocity 1·7005 feet per second, from which the discharge works out at 71,874,000 gallons per day.

As it was uncertain what portions would ultimately require to be lined, and what parts of the rock would resist the action of the water and the atmosphere, the whole aqueduct was taken out of the full dimensions given above. Where lining was necessary, 12 inches was considered to be thick enough, and this left rather more than the required area of water section, taking the value of n at 0·0184, which is the average value in the case of the lined parts of the old aqueduct. The dimensions within the lining are—9 feet wide at the bottom, 10 feet wide at a height of 6 feet above the bottom, and 9 feet high (Fig. 7, Plate XIX.). With a depth of 7 feet of water the following values are obtained :—

Area of water section = 64·82 square feet = A.
Wetted perimeter = 22·58 lineal feet = p.
Hydraulic mean depth = $\frac{A}{p} = \frac{64·82}{22·58} = 2·8707 = r$.
Inclination = $\frac{h}{l} = \frac{1}{5500} = 0·000,181,8 = s$.

With $n = 0·0184$, the value of c becomes 96·0, the velocity 2·1926 feet per second, and the discharge 76,743,000 gallons per day.

So long as the concrete lining preserves its smooth surface, the value of n will, no doubt, be less than that taken in the above calculation, but by the solvent action of the water upon the cement, it may ultimately become greater.

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6. CONSTRUCTION OF THE AQUEDUCT.

For the purposes of construction, the aqueduct was divided into seven sections. These are described in the table on page 244, which shows the length of each section, the average value of c in equation (1) in the old aqueduct, the date when let, the names of the contractors, and the amounts of the contracts.

This subdivision was made so as to enable those portions of the aqueduct, where the greatest resistance to the flow was experienced, to be duplicated in the order of their resistance. The first section taken in hands was the Mugdock tunnel, No. 7 in the table, in which the value of c in equation (1) in the old aqueduct was 56·89, causing the damming back of the water in the Blane Valley. Then followed the Duchray and Kelty Diversion, No. 3 in the list, where the values of c varied from 67·7 to 76·4, forcing the water back upon the long aqueduct bridges at Coulegarton. Then sections Nos. 6 and 2 were let, No. 6 first, as it was the longest, and these were followed by sections Nos. 4 and 5.

The first section in the table, the Loch Katrine inlet and tunnel, is not yet let nor will it be for some little time, as up till now the water in the loch has never been drawn down to its lowest level, and therefore an increased inclination, and consequently a greater velocity can be obtained in this part of the old aqueduct. If the co-efficient of resistance remains constant, this tunnel, if run full, or 8 feet deep at the inlet end, will discharge 52 million gallons per day.

The first contract was let in January, 1886, and allowing four years from this time for the completion of those recently commenced, the total expenditure upon the aqueduct will have been spread over 13 years, while that upon the Loch Katrine tunnel may be still longer delayed. The new Mugdock tunnel was brought into use on 31st October, 1890, and when the junction at its north end was opened, the water in the old aqueduct, finding a much freer escape, was lowered in level about two feet, and the influence of this lowering was felt for a distance of 8 miles to the north.

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New Aqueduct.—Table giving some details of the several contracts.

Sections.	Length.	Average value of c in old aqueduct.	Date when let.	Contractors.	Amount of Contracts.
	M. Ch. Yds.				
1. Loch Katrine inlet and tunnel, - -	1 26 15½	67·80	Not yet let	(Parliamentary estimate),	£56,760 0 0
2. Loch Chon section, -	3 32 14½	74·16	March, 1891	Jn. Waddell & Sons, Edinburgh,	70,337 17 8
3. Duchray and Kelty diversion,	6 23 11	72·41	Jan., 1887 / Dec., 1887	George Lawson, Rutherglen,	118,041 15 0
4. Black Rig diversion,	3 11 0	83·91	Jan., 1893	Morrison & Mason, Glasgow,	88,302 8 3
5. The Endrick piping—	2 34 0	92·94	May, 1894	Js. Young & Sons, Edinburgh,	16,998 6 2
Cast-iron pipes,			May, 1894	Macfarlane, Strang, & Co., Glasgow,	38,209 14 0
6. Blane Valley section—	5 35 7½	92·01	Mar., 1890	James Young, Glasgow,	116,023 5 0
Cast-iron pipes,			Sept., 1891	D. Y. Stewart & Co., Glasgow,	12,318 15 0
7. Mugdock tunnel, -	1 45 0	56·89	Jan., 1886	Morrison & Mason, Glasgow,	39,446 5 7
Total length,	23 4 4½				
Ironwork for the several contracts, - -			Let as required,	P. & R. Fleming & Co., and Kesson & Campbell,	2,251 17 1
				Total,	£558,660 8 9

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The Duchray and Kelty section was brought into use on 30th June, 1893, and when the connection between the two aqueducts was opened, the lowering of the level in the old aqueduct extended as far north as the loch. The completion of these two sections enabled about 4½ million gallons per day of additional water to be drawn from the loch.

The Loch Chon and Blane Valley sections, forming together about 9 miles of the aqueduct, are all but completed, and it is expected that they will be ready to receive the water early in 1895. All the anticipations of increased supply to the city, by the use of the two sections already completed, have been realised, and there appears every prospect that the increasing demand for water in the city will be fully met, as the other parts are from time to time brought into operation.

The interest upon the cost of the new works has, up to this time, been met out of revenue, without adding to the water rates, in fact the domestic rate was reduced in 1890 by one penny in the £ of rental, and a concession made in favour of the consumers by meter. The sinking fund applicable to the new works comes into operation in a year or two, and then the rates may have to be raised for a time.

For the first 9½ miles from Loch Katrine the aqueduct passes through the metamorphosed mica schist of the lower silurian system, the beds of which vary greatly, both in hardness and colour, some even at great depths under the surface, retaining, or having again returned to the consistency of clay. Then follows the old red sandstone for a length of 4¾ miles, with the well known conglomerate at its base, through which the aqueduct passes for 20 chains. The Blane Valley section passes for its whole length through the calciferous sandstone series, consisting of soft red and white sandstone, with beds of shale; and lastly, the Mugdock tunnel through a mass of whinstone and volcanic ash. Except in a few places in the south part of the old red sandstone, and in the Blane Valley, very little water was encountered.

The tunnels were first lined out above ground by a 6-inch transit theodolite, and then observatories, from 6 to 30 feet high, built on

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the highest points, in which transit instruments, 30 inches long, with 2¾-inch object glasses, by Elliot Brothers, of London, were mounted. All the principal tunnels had long base lines to work from, and the faces in all cases met exactly as to line, or within an inch of it. One of the shorter tunnels had two angles in it, at each of which there was a shaft, and here the error was three inches. Another was worked for 366 yards from a shaft with a base of 4 feet 6 inches, with an error of only ⅞-inch.

All the tunnels, with the exception of the one 2½ miles long on the Kelty section, were driven without shafts. In the case of the long tunnel, a shaft was put down at each end, and the distance between the two farthest faces was reduced to two miles. Shafts were generally put down where there was a change of direction, to facilitate the setting out of the line under ground. All the shafts were filled in after the tunnels were completed.

The tables on pages 247 and 248 give the lengths of all the principal tunnels and other works :—

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Table showing the length of the principal tunnels and other works.

Description.	Lengths of tunnels.	Short tunnels under 200 yds. long.	Open Cuttings, Chambers and Bridges.	Two lines of 48-in. syphon pipe.
	Lin. Yds.	L. yds.	L. yds.	L. yds.
Loch Katrine tunnel,	2,347½			
Loch Chon contract—				
North Frenich tunnel,	1,447½			
South Frenich tunnel,	833½			
Dow of Chon tunnel,	1,673			
Blaruskin tunnel,	1,319	597½	128	
Duchray and Kelty diversion—				
Coire Eirigh tunnel,	2,035			
Meadhonach tunnel,	610			
Blairvaich tunnel,	1,613			
Kelty long tunnel,	4,594			
Corrie Burn tunnel,	440			
Lossnaugh tunnel,	476	233	1,076	
Black Rig diversion—				
Green Burn tunnel, north,	505			
Green Burn tunnel, south,	249			
Black Rig tunnel,	4,327	...	441	
The Endrick piping—				
Two lines of 48-inch pipes,	...	...	22	4,246
Blane Valley section—				
Killearn tunnel,	1,850			
Lettre tunnel,	1,011			
Sauchie tunnel,	882			
Dumgoyne tunnel,	2,283			
Ballewan tunnel,	1,689	231	447	
Blane piping,	...	...	...	1,184½
Mugdock tunnel,	2,674		76	
	32,858½	1,061½	2,190	5,430½

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Summary—	M.	Ch.	Yds.
Long tunnels, - - - -	18	53	12½
Short tunnels, - - - -	0	48	5½
Open cuttings, chambers and bridges,	1	19	12
Syphon pipes, - - - -	3	6	18½
	23	48	4½

All the tunnels in the silurian, the old red sandstone, and in the whinstone, were worked by compressed air and Larmuth's hirnant rock drills, mounted on M'Culloch's carriages. The air compressors were by various makers, the pressure used being from 60 to 65 lbs. per square inch. The air pipes were of wrought-iron, and were usually 3 inches diameter, but those used for the Kelty long tunnel were 4 inches, and for the Mugdock tunnel 6 inches diameter, the larger pipes being the most efficient. The cylinders of the rock drills were 3¼ inches diameter, and three sizes of drills were used for each hole, viz., 2¼, 2, and 1¾ inches. In hard rock, rose pointed drills were used, and the shot holes were from 3½ to 4 feet deep, and in some places at the side of Loch Chon 22 holes were put into the face at each round, and in the conglomerate as many as 28 holes were required. About 30 minutes were required to bore one of the holes, and a round of holes took from 7 to 9 hours. The explosive used was chiefly gelagnite, and of this 25 to 27 lbs. were generally used for each round. In the softer rocks met with in the southern part of the old red sandstone, and in the Blane Valley, the driving was mostly carried on by hand, and gunpowder was often used.

The progress made with the driving varied very much. Stoppages had to be made for timbering or lining the soft beds, and occasionally the air compressors, and the drilling machines got out of repair, but for 15 months, in the hard rock in the Loch Chon section, the progress at one of the faces was 24 yards per month of four weeks; for 12 months in the Kelty long tunnel it was 44 yards per month; in the conglomerate for 12 months it was 27 yards per month; and in the whinstone of the Mugdock tunnel for 13 months it was 49 yards per month. In the softer rocks of the Blane Valley, where

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the driving was by hand, the progress ranged from 22 to 35 yards per month.

The lights used were flaming paraffin lamps, and at all the faces where compressed air was used the ventilation was generally satisfactory. At some of the faces worked by hand, air was forced in by fans, and here candles were used, but at all these faces the air was usually unpleasantly foul.

A considerably greater length of the aqueduct than was first expected had to be lined, and as lining costs about £6 per lineal yard, the total cost of the aqueduct has been increased. The proportion of the tunnels which required lining is given in the following table:—

Proportion of Lining in Tunnels.

	Length of tunnels.	Lined all round.	Side walls on both sides.	Side walls on one side.	Not lined.
	Lin. yds.	%	%	%	%
1. Loch Katrine tunnel,	Not yet let.				
2. Loch Chon section,	5,870½	38·5	12·7	...	48·8
3. Duchray and Kelty diversion, -	10,001	33·5	3·8	2·5	60·2
4. Black Rig diversion,	In progress.				
6. Blane Valley section,	7,946	75·7	0·5	0·6	23·2
7. Mugdock tunnel, -	2,674	34·9	7·0	2·9	55·2
Total,	26,491½	47·5	5·1	1·4	46·0

Concrete was exclusively used, the hardest and best of the spoil from the tunnels being used for this purpose, and where there was not enough of this, suitable stone was specially quarried, as in the case of the Blane Valley, where whinstone was used. The stone was broken in stone crushers, and passed into revolving cylinders perforated with holes 2 inches diameter, the finer material, which passed through ⅜-inch holes, being separated and used as sand, which purpose it served better than river or pit sand.

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The object, of course, was to make water-tight work, and after a few trials, the proportions fixed upon were, 3 measures of broken stone, 2 measures of sand, and 1 of cement. The cement was all carefully tested, and had to fulfil the following conditions. It must have been manufactured on the Thames or Medway; must be ground so fine that the residue upon a sieve of 5776 meshes to the square inch (equal to 76 per lineal inch) shall not exceed 10 per cent. by weight; and must, when mixed neat, placed in a mould, and immersed in water after having set, be capable of resisting a tensile strain of 350 lbs. per square inch at the end of seven days. Some difficulty was experienced in the early stages of the work in getting cement ground sufficiently fine, but as the demand for finely ground cement has greatly increased in recent years, the makers have found it to be to their advantage to put up more powerful grinding machinery, and there is now no trouble in this respect.

To avoid all questions with contractors as to the quantity of cement being put into the work, it was all paid for as it was delivered into the cement stores on the works, and though under this arrangement more cement may have been used than actually necessary, it was not found that it was in any sense wasted, or even recklessly used.

The minimum thickness of concrete for the lining of the tunnels was 12 inches, but as the rock cuttings were very irregular, the actual quantity of concrete required was always in excess of this. The average thickness was rarely less than 15 inches, and where the rock came away in large masses, the concrete sometimes averaged 18 inches thick. To ensure that reasonable care would be taken to keep the tunnels in proper shape when being driven, the contractors were paid for 15 inches of lining only, whatever thickness was required. Where the rock was very soft, however, or where it appeared necessary to provide additional strength, the lining was increased in thickness, and the whole material ordered to be put in was paid for.

The bottom of the aqueduct has a concrete invert throughout its whole length. In hard rock no special excavation was made to

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receive the invert, but in soft ground it was made 6 inches thick in the lowest part. The invert has a versed sine of 6 inches, and is brought to a smooth surface on top with cement mortar.

The average contract prices for a few of the principal classes of work, and the quantities of concrete paid for, for the lining, are given in the following table:—

New Aqueduct.—Average of some of the contract prices.

Driving tunnel, - - -	£7	16	8	per lin. yd.
Enlarging tunnel for 12-inch lining, $1\frac{1}{4}$ cub. yds., at 12s 6d, -	0	15	7	„
Concrete lining, including cement,	1	11	6	per cub. yd.
Lining of 12-inch side walls and arch, 3·75 cub. yds., at 31s 6d, -	5	18	6	per lin. yd.
Lining of 18-inch side walls and arch, 5·5 cub. yds., at 31s 6d, -	8	13	9	„
Concrete bottom of tunnels, -	1	0	0	„
Total cost of tunnel, with 12 in. lining,	15	10	9	„
Portland cement, - - -	2	10	0	per ton.

The intention of keeping the new aqueduct underground as far as possible has been so far carried out that there are only five short aqueduct bridges on the whole line, and with the view of making them as enduring as possible the following construction was adopted (Fig 9, Plate XIX.). The width of the bridges over the spandrils is 21 feet 6 inches enclosing the water way, which is 10 feet wide at the springing of the arched top. This difference in width of 11 feet 6 inches is occupied by—1st, the outside spandrils and wing walls, each 2 feet 6 inches thick; 2nd, by air spaces of 3 inches between the outside walls and the aqueduct; 3rd, by the side walls of the aqueduct itself, which are each 3 feet thick at the top. The thickness of the arches of the bridges varies from 2 to $2\frac{1}{2}$ feet according to their span, and the least thickness of the cover of the water channel is 24 inches, put in in two layers, each 12 inches thick, which are not intended to adhere to each other. The air spaces extend the whole length of the exposed part of the bridges, and

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have drains led away from them so that any leakage from the aqueduct may be detected at once. By this arrangement it is expected that the influence of frost and the heat of the sun will be prevented from reaching the water channel inside.

The outside quoins of the arches, the string courses, and the copes are all of large sized ashlar, and the facing of the spandrils and wing walls is of square dressed rubble. In the three most northerly bridges the ashlar is of granite from Ben Cruachan, and the squared rubble from a trap dyke in the vicinity of the crossing of the Duchray Water, where some very good stone was got. The two other bridges occur on the Blane Valley section, and there some excellent white sandstone was obtained and was used for all the ashlar and squared rubble. All the internal parts of the bridges are of concrete.

The object of the junctions which have been made between the old and the new aqueducts has been already referred to, and their construction is shown by Figs. 10 and 11, Plate XX. The shutting off and turning on of the water is effected by stop planks, working in grooves 3 inches deep, cut in blocks of granite built into the side walls of the aqueduct, the weight of the planks being adjusted so that two men can handle them easily. The spaces for working the stop planks are enclosed by arched chambers, and these afford sufficient ventilation and easy access to the aqueducts for examination and repairs. The chambers are provided with overflows and discharge valves, and gratings are placed in them across the aqueducts to intercept any floating matter that may get into the water. The ventilating shafts attached to the chambers are arranged to receive hoisting tackle in the event of any extensive repair being required in the aqueducts. These shafts are of masonry, but all the other parts of the chambers are of concrete.

Chambers for access are also placed near the bridges, and at other convenient points, and these are provided with overflows and discharge valves. (Fig. 14, Plate XX.)

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7. THE SYPHON PIPES.

The inverted syphon pipes, which carry the water across the valleys, are important features of the works. The Duchray Valley has been avoided by the new aqueduct, as has been already explained, but there still remains the Endrick Valley, 2 miles 34 chains wide, and the Blane Valley, 54 chains wide.

Some observations made upon the discharge of the first 48-inch pipe, which was laid on the line of the old aqueduct, in the Endrick Valley, were discussed before the Institution, by the late Professor Rankine, in 1869,* when he showed that the discharge corresponded closely with the formula proposed for clean uncoated cast-iron pipes, by M. Darcy, in 1857. At the date of the observations, the pipe had been in use for eight years, and tubercles had begun to form, especially in the bottom of the pipes. The value of c in the general equation for the velocity (equation 1), was found to be 112·3. The corresponding value of n in Kutter's formula (equation 3), is 0·01337, which is a little greater than that found by Kutter for ashlar and brickwork. But the tubercles in a pipe continue to increase in number and size, and in 1887, when three pipes had been laid in the Endrick Valley, the average value of c had fallen to 92·94, and n in Kutter's formula had risen to 0·0156. The three pipes were—a 48-inch, 27 years in use; a 36-inch, 19 years in use; and another 48-inch, 10 years in use. In these calculations, however, the effective area of the pipes is taken from their original diameter, which, on account of incrustation, is not the correct area, but this it was impossible to ascertain.

In fixing the diameter of the pipes for the new aqueduct, 48 inches was thought to be as large as it was prudent to use, and as regards their number, if the value of c is taken at 93, and the effective fall at 1 in 960, the discharge of each will be $20\frac{1}{3}$ million gallons per day. Three such pipes are too few, and four too many, for the desired purpose, but arrangements are made for ultimately putting in four, leaving the question of number to be determined when the

* See Transactions of the Institution of Engineers and Shipbuilders in Scotland, Vol. XII., page 136.

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necessity arises, and leaving also the option of scraping out the pipes which may then be in use. Two 48-inch pipes only are being laid at present.

Various systems of jointing large pipes have been tried in connection with these works. The first pipes laid had the ordinary spigot and socket, lead and yarn joints, but those laid during the last twenty years have had chiefly turned and bored joints. In both systems, the socket is the weakest part of the pipe, on account of unequal strains being set up in the cooling of the metal, and by the bursting stress brought on it in making the joint. By the caulking up of the lead in the case of a lead joint, and by the driving home in the case of a turned and bored joint, the stress induced is increased by the pressure of the water inside the pipe, and failures usually occur by a V shaped piece being blown out at the socket end. In recent years, several long lengths of large pipes have been laid with mild steel collar joints, as shown by Fig. 12, Plate XX., and in no case has either the pipe or the joint failed. This joint seems to satisfy theoretical considerations, as the steel is put into tension by the setting up of the lead, and its great elasticity and tenacity is brought into play, while the end of the pipe is put under compression, which cast-iron can best resist, and this stress operates in a direction opposed to that of the pressure of the water. The pipes are cut at both ends in a lathe to the proper length, and are placed about $\frac{1}{4}$ inch apart. Clay fillets are placed outside at each end of the collar, and a spring steel ring inside the pipe, and the joint, including the space between the two pipes, is run quite solid with lead, which, therefore, does not present any surface to the water whereby it could be blown out. All the syphon and other large pipes above 3 feet diameter, connected with the new works, have been, or will be, jointed in this way. They are each 12 feet long, and the 48-inch pipes weigh from 3 to $4\frac{1}{2}$ tons each. The steel collars are rolled out of the solid, are 6 inches long, and are hollowed out $\frac{1}{8}$-inch inside to assist in holding the lead, which is caulked up on the two external faces, as well as in the space between the two pipes inside.

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The comparative cost of this and an ordinary lead and yarn joint may be put as follows:—

For an ordinary 48-inch lead and yarn joint, - - -				£1	5	0
For a steel collar joint, - -	£2	6	0			
Cost of collar, - - - - -	1	13	6			
	3	19	6			
Deduct cast-iron in socket, - -	1	12	0	2	7	6
Increased cost of collar joint, or 5s 8d per lineal yard. -				£1	2	6

Where curves occur in the line, and where the inclination varies vertically, the necessary cant is given to the pipes by cast-iron bevelled collars as shown by Fig. 3, Plate XX., the outer belt of the sockets being strengthened by welded steel hoops which are shrunk on while hot.

Manholes for gaining access to the inside of the pipes are provided at intervals of about 500 yards.

Three bridges are required in the Endrick Valley for carrying the pipes:—one across a public road, another across the Forth and Clyde Railway, and the third across the River Endrick, the latter having a span of 84 feet. They consist of steel web girders, supported upon masonry abutments, and do not call for a detailed description. Girders are placed for two lines of pipes only, but the masonry is prepared for all the four lines. At the crossing of the Blane Valley two bridges were required, both of which are of masonry.

As with the other parts of the aqueduct, the principle of protecting every part of it from contact with the atmosphere has as far as possible been carried out with the pipes. Except on the girder bridges they will all be covered with earth, and some of the exposed pipes on the old aqueduct will be treated in the same way.

The syphon pipes are connected to the built parts of the aqueduct at either end by a chamber, the chambers at the upper or northerly end being furnished with valves with gearing for closing

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rapidly in the event of a pipe bursting, and at the lower end with reflux valves which close automatically. Alarms attached to each pipe will be placed in the watchmen's houses as in the case of the existing pipes.

8. THE NEW SERVICE RESERVOIR.

To complete the duplication of the works, it was necessary to have an additional service reservoir near the city; in fact, this was anticipated, and authority to construct such a reservoir was obtained in 1882, three years prior to the Act for the duplication of the aqueduct. The ground to the east of the present Mugdock Reservoir seemed to offer itself as a convenient site, though the length of the embankment required was considerable.

Extensive boring operations were carried out and pits sunk, with the view of ascertaining the character of the foundation, and determining the depth to which it was probable the excavation for the puddle trench would have to be carried. These showed that beneath a layer of soil, peat, and sand, varying in depth from a few feet to 23 feet, there was rock throughout the whole length of the embankment, the rock being partly whinstone and partly sandstone. They also showed that the whinstone, of which there were five distinct masses, were flows resting at the west end of the embankment upon a thick bed of fine clayey shale, and at the northern part upon sandstone overlying the shale. The rocks of the district belong to the calciferous sandstone series, and in the construction of the adjoining Mugdock Reservoir, which was completed in 1859, there had been no difficulty in getting a water-tight foundation in the sandstone rock at a moderate depth, but the trench for the new reservoir turned out a very anxious and expensive piece of work.

The reservoir will have a water surface of 86¼ acres, an available depth of water for the city of 40 feet, and at that depth will contain 700 million gallons. The embankment is 1592 yards long, and 93 feet high above the bed of a small stream which flows through the site, has a puddle wall in the middle in the usual way, and has slopes of 3 to 1 on the inside and 2 to 1 on the outside. It has a

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crescent form in plan, commencing at the west end by a junction with the easterly embankment of the Mugdock Reservoir, proceeding in an easterly direction for 665 yards, and then turning towards the north.

Operations were commenced in 1883 upon what is now known as the Craigmaddie Reservoir, by the diversion of the public road to Strathblane which ran through the site, and by the diversion of the streams which ran into it. These preliminary works were completed in 1885, and the reservoir works proper were begun in July, 1886. The shale bed rose to within 30 feet of the surface of the ground at the western or Mugdock end of the embankment, and it was to this part that attention was first directed. The first and second whinstone flows were found to have come up on the top of the shale, and as the rock was fissured they were cut out and the shale laid bare. For the first 665 yards, although the trench averaged 42 feet deep, and a considerable part of it 54 feet deep, there was not much water to contend with, and there is nothing calling for special remark. (Fig. 9A, Plate XIX.)

It was in the northern part of the embankment that difficulties were encountered. The sandstone above the shale, of which there was a considerable mass, was found to be extensively fissured and crossed by faults, and it was necessary to cut it all out, and to follow the shale. The markings on the Ordnance geological maps of the district, and a special report by Mr James Geikie, of the Ordnance Survey, led to the belief that this part of the trench would lie along the strike of the strata, and that the shale bed would be found to follow a nearly horizontal line to the north, but this was found not to be the case, the shale continuing to dip irregularly at about 1 in 25. In this part of the trench there were two small caps of whinstone overlying the sandstone, but it was obvious that these could not have disturbed the sandstone below. At the extreme north end of the embankment, however, the fifth piece of trap encountered has come up in great mass, and at a lower level than the other flows, and this appears to have been the cause of the crushing of the sandstone.

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On the north part of the trench the shale was followed for 627 yards, and there the deep excavation terminated at a point where it was 193 feet below the original surface of the ground, the average depth of the cutting in this length being 130 feet. At the point where the deep part of the trench terminates, the water in the reservoir will be of no great depth, and it is expected that not much water will pass through the rock round the end of it, and to prevent any that may pass acting upon the puddle, the end of the trench, which finishes with a perpendicular face 142 feet high, is lined with a mass of concrete the whole width of the trench, 38 feet thick at the bottom, and 9 feet thick at the top, against which the puddle rests.

The remaining 300 yards of the trench bounds the shallow part of the reservoir, varies from 51 to 9 feet deep, and is excavated chiefly in whinstone.

The excavation of the deep part of the trench was completed in September, 1892, having occupied rather more than six years. After working for eighteen months, the first contractors resigned the contract, and there was some delay before the works were started again; but the chief hindrance was the great depth to which the trench had to be carried, and the amount of water met with in the deeper parts. The quantity pumped averaged from 400,000 to 450,000 gallons per day for nearly three years, and the greater part had to be raised 150 feet.

In the southerly half of the deep part of the trench, the rock was sufficiently sound to stand without timbering, but the northerly half was much fissured and broken up by faults and required to be timbered. To avoid any risk of the sides of the trench collapsing, large masses of rock were temporarily left in at intervals, and the excavation carried on by tunnelling below them, the trench at this place, for a time, presenting the form of a large honeycomb. As a further protection to the men working below, a benching, 9 feet wide, was formed on the top of the sound part of the rock on each side, to receive loose stones which, especially after frost, came away from the loose material above.

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The total amount of rock excavation in the trench was 168,000 cubic yards, and on account of the exceptional character of the work it was withdrawn from the contract, and was executed at the cost and risk of the commissioners. The total cost, including plant, pumping of water, contractors' profit, and all other charges, will be about £73,800. The time occupied interfered with the carrying on of the other works to such an extent that advanced prices had to be given to the contractors to the amount of £21,000.

During the six years occupied in sinking the trench, the other portions of the work were being carried on as far as this was possible. To enable the puddle filling to proceed, concrete pillars were built across the trench, as portions of it were cleared to the bottom, and, when the puddle reached the surface of the ground, the forming of the embankment was gone on with. There were five of these concrete pillars, varying in height from 32 to 64 feet. They are 9 feet thick at the top, and batter 2 inches to the foot at each side, a deep groove being formed on each side to receive the puddle. One of the pillars is in line of a tunnel, formed for the cleansing culvert out of the lowest part of the reservoir, and the pipes laid in it, where they cross the trench, are bedded in the concrete. The bottom of the trench at this point is 51 feet below the bottom of the reservoir.

During the early part of the operations, and where the trench was not very deep, the clay for filling it up was simply tipped on to platforms of planks laid in the bottom, from which it was wheeled and spread out in layers; but, as the depth of the trench increased, this manner of proceeding was found to be attended with danger to the workmen below. The contractors, therefore, devised a lowering apparatus, consisting of two platforms, one to ascend while the other descended; and upon these platforms the clay was placed in barrows, four at a time, and lowered into the bottom, where other workmen wheeled it away and spread it out. The rapidity of the ascent and descent of the platforms was regulated by steel wire ropes, worked by a steam winch, and the platforms were kept steady by guide ropes fixed at top and bottom. Three of these

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lowering apparatus were erected, and they worked in a most satisfactory manner. The maximum depth to which the clay was lowered was 133, 153, and 165 feet, respectively.

The embankment contains in all 293,760 cubic yards of puddle, 598,750 cubic yards of ordinary earthwork, and 44,000 cubic yards of stone facing. Including the Barrachan property, the extent of land purchased for the reservoir is 215½ acres.

The inlet works include an aqueduct 954 yards long, to convey 110 million gallons of water per day from the southerly end of the new Mugdock tunnel, and of a gauge basin and measuring pond. The old and the new Mugdock tunnels are connected at their southerly ends by a junction aqueduct and stop plank chambers, so that the flow of either or both aqueducts can be directed into either reservoir.

The outlet works, in addition to the cleansing culvert above referred to, consist of a valve tower, a straining well, and a discharge tunnel, 420 yards long, carrying two 42-inch pipes, similar to the corresponding works of the existing reservoir, and they do not, therefore, call for a detailed description.

The table on page 261 gives the dates when the several contracts connected with the reservoir were let, the names of the contractors and the amounts of the contracts.

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Craigmaddie Service Reservoir.—Table giving names of contractors and the amounts of the contracts.

Contracts.	Date when let.	Contractors.	Amount of Contract.
			£ s. d.
Road and stream diversions,	Sept., 1883	Mr John Pollok, Glasgow,	11,058 10 0
Cast-iron pipes,	Sept., 1883	D. Y. Stewart & Co., Glasgow,	3,978 2 6
Reservoir works,	May, 1886	Robt. Carlisle & Co., Belfast,	*19,971 1 0
Reservoir works,	May, 1888	Morrison & Mason, Glasgow,	129,649 13 10
Trench, cost of,	...	Do.	†59,349 18 7
Increased rates,	1st Feb.,'92	Do.	20,003 7 6
Cast-iron pipes	May, 1886	Robt. Laidlaw & Son,	658 0 0
	Feb., 1894	D. Y. Stewart & Co.,	5,330 17 6
Valves and other ironwork,	Jan., 1894	Glenfield Co., Kilmarnock,	6,994 17 6
		Total,	£256,994 8 5

9. NEW MAINS TO THE CITY.

In addition to the four 36-inch mains from the Mugdock Reservoir, it is intended that there shall ultimately be other four mains from the Craigmaddie Reservoir; but only two of these are being laid down in the meantime. The roads approaching the city from the west and north-west are already so much occupied by water and gas mains, that the Balmore Road, leading to the north-east part of the city, has been selected for the new mains, the first 3½ miles being by a moderately direct line through the fields. Five bridges are required, three across railways, one across the Allander water, and one across the River Kelvin. The pipes are carried between steel web girders, similar to those already

* This is the amount of work executed by this firm.

† Exclusive of part executed by Messrs Carlisle & Co.

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referred to for the syphon pipes, and the masonry abutments are prepared for ultimately receiving four lines of pipes. The Forth and Clyde Canal, near Lambhill, is crossed under, in tunnel, but as the canal, at the point selected for the crossing, is in rock cutting, the work does not possess any special feature. Junctions will be made between the mains at three points, and watchmen's houses, with alarms in them, are about to be erected—all as in the case of the existing mains. The pipes are each 12 feet long, and have partly plain socket joints, and partly turned and bored joints. On the bridges, at the crossing of the canal, and at some other important points, they have steel collar joints. The outer belt of all the sockets have steel rings shrunk upon them, and the curves and changes of inclination are made with bevelled cast-iron collars, as in the case of the syphon pipes.

Where the mains pass along public roads, the current contracts include one main only, as it was not practicable to lay both lines at the same time, and maintain space for the traffic.

The following table gives the names of the contractors for this part of the work, and the amounts of the present contracts :—

New Mains to the City.—Table giving names of contractors and amounts of contracts.

Contracts.	Date when let.	Contractors.	Amount of Contract.
			£ s. d.
Cast-iron pipes,	July, 1892	Robt. Laidlaw & Son, Glasgow,	61,272 1 6
Do.	July, 1893	Macfarlane, Strang, & Co., Glasgow,	5,766 14 0
Pipe-laying and masonry,	July, 1892	Mr James Young, Glasgow,	21,545 8 3
Valves,	Feb., 1893	Hanna, Donald, & Wilson,	852 4 0
Steel girders,	Aug., 1893	William Baird,	1,090 19 0
Other iron work,	June, 1894	P. & R. Fleming & Co.,	217 3 5
		Total,	£90,744 10 2

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10. WORKS AT LOCH KATRINE.

The level of the water in Loch Katrine is to be raised five feet above its present top water level, but this work has not yet been entered upon. For the privilege of using the loch to this additional extent for storing water, the proprietors agreed to accept the sum of £20,250. It is intended to place the new dam at the outlet immediately below the present one. The river channel here is narrow and in rock, and the work will be simple and similar to the present outlet. Some miles of new road will have to be formed on the north shore of the loch, in lieu of parts of the existing public road, which will be submerged. It was necessary to purchase the hotel at Stronachlachar, the site of which will be flooded, and this was done by agreement with the proprietor and tenant for £5500, and a new hotel has already been erected. New steamboat piers, or landing stages, to suit the varying levels of the loch, which may now occasionally amount to twelve feet, will have to be erected at the top and bottom of the loch, and some new boat houses and boat piers will be required. An inlet to the new aqueduct will have to be constructed, and the inlet to the present aqueduct altered to suit the raised level of the loch; but the details of all these works have not yet been considered.

Under the Act of 1855, the quantity of water that could be drawn to the city from the loch was limited to 50 million gallons per day, but by the Act of 1885 this restriction was removed, and now as much water can be taken as the loch will yield. In addition to the 65 million gallons per day which it is expected to supply for city use, 5 million gallons per day have to be sent, as at present, from the outlet, down the Achray water to supplement the storage in Loch Drunkie and Loch Vennachar, from which lochs the compensation water to the River Teith is supplied, making the daily draught upon the loch 70 million gallons, which amounts to 48½ inches of rainfall per annum over the drainage area.

The following table gives the storage capacity and other particulars of the loch as it stands at present and as it will be altered under the Act of 1885:—

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Table showing capacity and other particulars of Loch Katrine.

	At present.	As it will be altered.
Top water level above Ordnance datum,	368 feet	373 feet
Drainage area, -	23,192 acres	23,192 acres
Area at raised level, -	3,058·7 acres	3,150·2 acres
Range of level, -	7 feet	12 feet
Storage capacity, -	5,623,581,250 galls.	9,849,383,044 galls.
Storage capacity in inches of rainfall over drainage area, - -	10,688 inches	18,719 inches
Supply to city per day,	50,000,000 galls.	65,000,000 galls.
Supply to Achray Water per day, - -	5,000,000 galls.	5,000,000 galls.
Total supply,	55,000,000 galls.	70,000,000 galls.
Total supply in inches of rainfall over drainage area, - -	38·148 inches	48·558 inches
No. of days supply stored,	102¼ days	140¾ days

In estimating the quantity of water obtainable from a given district, it is usual to take the average yearly rainfall during the three consecutive driest years, after making deductions for evaporation and other losses, but to enable the whole flow of the streams during such a period to be available, it is necessary to have storage for about six months' supply. Since rainfall observations were commenced in this district, in 1853, there have been two periods of three years each in which the fall was a minimum. These have been as follows :—

Periods of three consecutive dry years.

	At Glengyle.		At Glengyle.	On tunnel top.
	Inches.		Inches.	Inches.
1855	65·5	1878	82·0	65·7
1856	79·3	1879	87·0	66·6
1857	91·6	1880	69·0	62·4
Average	78·8	Averages	79·3	64·7

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The hill tops on the west and north sides of the drainage area rise from 1400 to 2000 feet higher than the gauge on the top of the tunnel, and therefore during these years an average of over 60 inches per annum might be collected, but it was not thought prudent to ask power to raise the level of the loch to the extent necessary to provide storage to render the whole of this rainfall available, and it was accordingly resolved to restrict it to the amount sufficient to enable a constant supply of 70 million gallons per day.

The driest single years during the 40 years have been as follow:

Glengyle Rain Gauge.—Dry years.

1855	1865	1870	1880	1887
Ins.	Ins.	Ins.	Ins.	Ins.
65·5	72·2	71·3	69·0	67·0

The six consecutive driest months have occurred in the following years:—

Glengyle Rain Gauge.—Periods of six consecutive dry months.

	1855	1865	1869	1870	1880	1887
	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
January,	1·8	...	...	...	...	...
February,	1·2	...	...	...	...	...
March,	7·5	4·2	2·9	1·8	...	...
April,	6·1	2·5	3·8	4·8	...	3·3
May,	3·2	5·7	1·6	10·4	1·1	0·8
June,	3·7	2·2	4·2	3·4	6·6	1·1
July,	...	5·3	6·0	3·4	4·6	6·2
August,	...	8·3	1·3	1·6	3·2	8·1
September,	...	...	...	...	3·2	1·9
October,	...	...	...	...	0·2	...
Totals,	23·5	28·2	19·8	25·4	18·9	21·4

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The longest droughts, however, measured by the quantity of water which flowed off the ground, were during 1869 and 1880, and the observed results of these droughts were taken to determine the amount of storage to be provided to maintain a uniform draught upon the loch of 70 million gallons per day. The gaugings of the quantity of water flowing out of the loch show that the drought in 1869 would have extended from the 9th of March to the 15th of September, a period of 190 days, reckoning from the day the water level of the loch began to fall, to the date when the loch would have begun to fill up again. During that time the quantity of water which flowed into the loch from the streams was equal to 7·169 inches of rainfall over the drainage area, out of a registered rainfall at Glengyle, at the top of the loch, of 21·8 inches, and of 17·4 inches at Loch Dhu in the adjoining valley to the south. The gaugings also show that during such a drought, storage to the extent of 18·108 inches of rainfall over the drainage area, or 136 days' supply, will have to be provided to maintain 70 million gallons per day. With the loch raised 5 feet above its present top water level, the storage will be 18·719 inches over its drainage area, being 321 million gallons, or 4¾ days' supply in excess of the quantity required. These figures are more concisely set forth in the following table:—

Drought of 1869 at Loch Katrine.

Duration of drought—from 9th March to 15th September,	190 days.
Assumed quantity of water drawn from loch during drought at 70 million gallons per day,	13,300 million galls.
Quantity drawn out in inches of rainfall over drainage area,	25·277 inches.
Quantity of water yielded by the streams during drought,	3,772 million galls.
Yield of streams in inches of rainfall over drainage area,	7·169 inches.
Storage required in gallons,	9,528 million galls.
Storage required in inches of rainfall over drainage area,	18·108 inches.
Rainfall during drought as registered at Glengyle, head of Loch Katrine,	21·8 inches.
Rainfall at Loch Dhu, in the Loch Chon valley,	17·4 inches.

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The drought of 1880 lasted from 25th April to the unusually late date of 7th November, a period of 196 days, 6 days longer than the drought of 1869. While the rainfall at Glengyle, during this drought, was 2·9 inches less, yet the quantity of water that ran off the ground in 1880 was 1·89 inches more than in 1869, arising, of course, from the manner in which the rain fell. The particulars of this drought are given in greater detail in the following table :—

Drought of 1880 at Loch Katrine.

Duration of drought—from 25th April to 6th November,	196 days.
Assumed quantity of water drawn from loch during drought at 70 million gallons per day,	13,720 million galls.
Quantity drawn out in inches of rainfall over drainage area,	26·075 inches.
Quantity of water yielded by the streams during drought,	4,768 million galls.
Yield of streams in inches of rainfall over drainage area,	9·062 inches.
Storage required in gallons,	8,952 million galls.
Storage required in inches of rainfall over drainage area,	17·013 inches.
Rainfall during drought as registered at Glengyle, head of Loch Katrine,	18·9 inches.
Rainfall at Loch Dhu, in the Loch Chon valley,	17·8 inches.

The gaugings also show that there were five weeks during the drought of 1869, and seven during 1880, in which the quantity of water flowing into the loch from the streams was less than the evaporation from its surface. During seven weeks this excess amounted to 0·1 inch per day.

A continuation of the tables of rainfall, as registered at the various gauges kept in connection with the works, contained in former papers, is given in the following table :—

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Rainfall in the Loch Katrine and Gorbals Districts.

	Among the hills round Loch Katrine.					On the lower ground by L. Vennachar.						Gorbals District.			
	At Glengyle, head of Loch Katrine.	On summit of hill above Tunnel at Loch Katrine.	On hills between Loch Ard and Loch Katrine. — Ledard.	At Loch Dhu.	Head of Duchray Valley. — Ben Lomond.	Between Glen Finlas and Ben Ledi.	At Bridge of Turk.	At Loch Drunkie.	At Loch Vennachar.	At the Inn at Aberfoyle.	At Mugdock Reservoir.	No. 1. — Waulk Glen Reservoir.	No. 2. — Ryat Linn Reservoir.	At Middleton	At Nether Cairn. — Black Loch.
Elevation,	380 ft.	830 ft.	1500 ft.	325 ft.	1800 ft.	1800 ft.	275 ft.	420 ft.	275 ft.	60 ft.	320 ft.	280 ft.	310 ft.	550 ft.	700 ft.
Date when gauges were fixed	1854	1861	1854	1861	1854	1854	1854	1861	1861	1854	1862	1854	1854	1855	1854
Averages to 1868 inclusive,	Ins. 92·0	Ins. 81·3	Ins. 85·9	Ins. 88·6	Ins. 90·5	Ins. 59·4	Ins. 59·4	Ins. 67·5	Ins. 61·2	Ins. 55·2	Ins. 49·0	Ins. 46·7	Ins. 44·9	Ins. 53·1	Ins. 54·7
Averages 1869 to 1882 inclusive,	94·1	77·4	68·0	81·0	82·4	56·2	70·9	65·5	58·7	58·6	47·8	46·96	48·84	54·17	58·33
1883, ...	100·60	85·60	67·20	84·90	82·40	55·20	74·50	69·40	67·20	63·80	54·40	49·95	53·80	60·95	63·40
1884, ...	107·90	89·50	72·00	95·60	95·10	50·70	83·00	75·90	72·30	63·20	59·60	51·80	55·10	62·85	64·90
1885, ...	84·10	64·50	66·00	79·70	85·60	50·00	69·60	62·30	56·60	53·70	41·90	40·40	40·90	50·50	52·40
1886, ...	81·10	53·80	59·90	71·80	69·80	47·60	64·70	58·70	54·50	48·60	48·50	44·55	46·25	53·90	54·65
1887, ...	67·00	41·20	36·70	57·00	61·00	35·10	47·85	46·15	43·30	29·85	36·60	36·90	38·20	44·75	44·60
1888, ...	89·40	61·90	61·05	75·50	73·60	53·55	62·80	61·65	55·60	56·50	44·95	43·65	44·75	51·00	52·95
1889, ...	76·30	59·60	47·15	62·50	70·80	38·90	48·35	47·50	43·65	48·95	39·00	38·30	39·50	45·05	48·90
1890, ...	95·10	82·80	54·74	78·50	84·80	51·50	68·75	65·00	54·90	56·15	53·80	53·05	54·60	59·95	63·55
1891, ...	94·40	83·60	57·00	82·50	86·40	47·45	65·50	60·90	56·15	57·85	46·88	51·05	52·40	57·10	55·40
1892, ...	89·60	76·30	57·40	72·30	74·50	47·00	61·75	62·75	55·95	58·60	48·10	49·05	50·20	55·05	59·75
1893, ...	91·90	81·10	45·95	71·80	72·70	40·10	53·10	53·70	46·40	50·60	43·85	42·95	44·30	47·90	45·95
Averages 1883 to 1893 inclusive,	88·85	70·90	56·83	75·65	77·88	47·01	63·19	60·36	55·14	52·98	47·05	45·60	47·27	53·54	55·13

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11. LOCH ARKLET.

The works at Loch Arklet will consist of an embankment across the valley, placed a considerable distance westwards of the present outlet of the loch, a discharge tunnel at the lower or Loch Lomond end, and a tunnel about 700 yards long at the upper end, by which the water will be drawn into Loch Katrine. The table below gives the drainage area, storage capacity, and other particulars of the loch as it will be altered. As the storage provided amounts to nearly 30 inches of rainfall upon the drainage area, it is expected that 60 inches will be available on the average of three consecutive dry years, which will give 10 million gallons per day for the city, and 1,737,000 gallons per day for compensation water.

The preliminary bores put down in 1884 to ascertain the probable depth and nature of the foundation for the embankment, were not sufficiently numerous to determine the best position for the work, but as far as they went they showed that the rock in the bottom of valley rose in level to the west, and it is, therefore, probable that the embankment will be moved further in that direction than at first intended, and that it will be a masonry structure. The execution of this work will not be entered upon until the quantity of water Loch Katrine will yield is all taken up by the city. The right to use the loch for the purposes of a reservoir has been acquired from the proprietor for the sum of £3,000.

Appendix IX.—Table of capacity, etc., of Loch Arklet.

Top water level above Ordnance Datum, -	480 feet.
Drainage area, - - - - -	3,103 acres.
Area at present level, - - -	207 acres.
Area at raised level, - - -	409 acres.
Range of level, - - - -	25 feet.
Storage capacity, - - - -	2,059,306,708 galls.
Storage in inches of rainfall over drainage area,	29·252 inches.
Supply to city per day, - - -	10,000,000 galls.
Compensation to Arklet water per day, -	1,737,000 galls.
Total to be drawn from loch -	11,737,000 galls.
Total quantity to be drawn from loch in inches of rainfall over drainage area, - -	60·852 inches.
Number of days supply stored, - -	175½ days.

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12. ESTIMATES AND COST OF WORKS.

The table on page 271 gives the Parliamentary estimates for the works which have been described, and their cost so far as they have been executed, including inspection and all other charges except engineers' salaries. The estimate for the Act of 1885 included only one line of 48-inch pipes in the valleys, but in executing the work two lines have been laid, and the additional cost has been included in the table. The Loch Chon section, the Duchray and Kelty diversion, the Blane Valley section, and the Mugdock tunnel, comprising 16½ miles of the aqueduct, are either finished, or are so far completed as to enable their ultimate cost to be nearly ascertained. Taking an average throughout, it appears that the aqueduct will be constructed for the estimate, though the deviations made in the line of 1885 render a strict comparison impossible.

On the other hand, the cost of the Craigmaddie Reservoir is likely to exceed the estimate by £100,000, but this excess is nearly covered by the cost of the trench and the advanced prices which had to be paid for the other works which the trench delayed. It was also thought desirable to purchase all the land between the old and the new service reservoirs, so as to throw it out of cultivation and thus diminish the chances of pollution.

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Parliamentary estimates and cost of the works as at 30th November, 1894.

	Parliamentary Estimates.	Cost to 30th Nov., 1894.
New aqueduct—		
Loch Katrine inlet and tunnel,	£57,130 14 0	£48 3 8
‡Loch Chon section, -	89,862 6 0	94,747 6 8
†Duchray and Kelty diversion,	220,705 10 0	185,167 11 0
Black Rig diversion, -	98,770 17 0	25,938 0 4
The Endrick piping,	76,780 0 0	11,661 5 7
‡Blane Valley section, -	151,350 17 0	160,182 4 2
*Mugdock tunnel, - -	51,906 5 0	45,513 14 11
Total for aqueduct,	£746,506 9 0	£523,258 6 4
Craigmaddie service reservoir, Act 1882, £150,000 0 0		
Do. works included in Act of 1885, 19,042 4 6		
	169,042 4 6	§269,011 0 10
‡New mains to the city, -	118,244 1 9	92,609 15 4
Works at Loch Katrine, -	10,932 9 3	2,106 8 11
Works at Loch Arklet with conduit, - - -	60,121 1 0	0 0 0
Lands and Compensations,	100,000 0 0	67,715 2 8
Total, - -	£1,204,846 5 6	£954,610 14 1

13. PURCHASE OF FEUING RIGHTS AT THE LOCHS.

The preservation of the purity of the water at its source is of paramount importance. The provisions of the Water-works' Clauses Act, 1847, apply to gross cases of pollution only, such as bathing, throwing filth, and washing clothes in reservoirs, or allowing water from a sewer or refuse from a gas work to flow into any stream or reservoir used for water supply, but the Act does not give sufficient protection against the admission of the refuse water from farm houses and other buildings existing upon a water shed prior to its being appropriated for the supply to a town. The Commissioners

* Completed.
† Completed. Accounts not closed.
‡ Nearly completed.
§ This account includes £24,175 7s 4d for lands and compensations.

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accordingly entered into agreements with the owners of the lands round the lochs, which were confirmed by the Act of 1885, whereby, if the appliances in use at any building are, in the opinion of the Commissioners, insufficient to prevent the fouling of the water, they may enter upon the lands, and at their own cost construct such drains, cesspools, and receptacles as they may deem necessary, after which the proper use and the regular cleaning out of the apparatus provided is laid upon the owners and occupiers. There are very few houses within the water shed of the lochs, and at only two of them has it been found necessary to construct the appliances provided for.

The desire of people of sufficient means to escape from the city for a portion of the year, and the recent development of means of communication, has resulted in the conversion of many places favoured with natural attractions into centres for villa residences. The shores of Loch Katrine, with the associations that Scott has thrown around them, appeared a likely place for such a development in the near future, and to protect the water from the unavoidable pollution which would follow, agreements were made with the proprietors, which were confirmed by an Act in 1892, whereby, for payments amounting to £17,000, they became bound not to erect any additional dwelling houses or other buildings within the water shed of the lochs, extending to an area of 26,295 acres, or to feu or lease ground for that purpose, or to place on Loch Katrine a greater number of steamboats than are required for the tourists' traffic, nor to give a right to any person not having a house within the water sheds to place boats of any kind on the lochs.

With the same object in view, that of preserving the purity of their water supplies, the municipalities of Liverpool, Manchester, and Birmingham have, at great cost, purchased absolutely the whole area of their respective water sheds, but it is considered that all, or nearly all, the advantages secured to these cities by purchase will be derived by Glasgow through the prohibition of feuing and erecting houses.

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The discussion of this paper took place on 30th April, 1895.

The PRESIDENT said that he did not know whether any one would feel inclined to discuss this most elaborate and valuable contribution to their Transactions, as Mr Gale's papers had always been.

Mr E. P. HETHERINGTON asked what system was adopted to scour the syphon in the dips free of the gravel and sediment likely to settle there. At the Paris Exhibition, a few years ago, he had noticed a 3-inch glass syphon, with a tank at each end. Into the inlet end of the syphon was placed a wooden ball, to show through the glass how gravel and sand could be removed out of the dip of the syphon. The flow of the water drove the ball forward, it being rather less in diameter (about $2\frac{3}{4}$ inches) than the inside diameter of the pipe. With the force of the water scouring past the ball, it drove big pebbles, sand, and the ball right into the other tank on the opposite side. He thought it rather clever, and he had never seen anything of the kind in this country. This was the system that the Municipal Government of Paris adopted to clear the sediment and stones away from the bottom of the syphons and up the incline of the opposite side. He did not know whether there was anything of that kind in connection with the Glasgow Water Works system, and he would like to know.

Mr GALE said that he had never seen anything lodge in the bottom of the syphon pipes. The velocity there was considerably greater than it was in the aqueduct itself, so that whatever was swept forward by the aqueduct was certain to be swept out of the syphon pipes. He did not know why they should find anything else in Paris. In some of the pipes in Glasgow, if gravel got in when pipes were being laid at first or mended afterwards—if gravel got in where the current was very small, it would remain there, but along the line of the aqueduct, which was the question that was put, nothing could get into the pipe except what the current would sweep away. They knew a current of three or four feet a second would carry forward very large stones. There was an idea that air collected at the top of the bends in the pipes in the ordinary

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working. When pipes were filled first of all where there were elevations, the air must be liberated from these elevations, but in ordinary working the air did not collect in the pipes. The pressure that was usually upon the pipe was sufficient to force the air into the water and so absorb the air.

Mr HETHERINGTON asked whether the force of the water travelling at three or four feet per second was sufficient to lift large pebbles up the incline to the opposite side of the syphon.

Mr GALE—Yes, that is so.

Mr HETHERINGTON said that it was one of the most interesting things that he had noticed in the Exhibition.

Mr GALE said he understood that the sand and gravel were put in purposely to show the experiment.

Mr HETHERINGTON—Yes, quite so.

Professor BARR thought this was a paper that any institution in the world would be very proud to receive, and he suggested that as the paper could not be properly discussed at present, the discussion should be adjourned to the beginning of next session. He thought it would strike every one that the formula deduced by Ganguillet and Kutter was one of an impracticable description. The reason for that was that attempts had been made to find a formula that would give the rate of discharge in a channel. Among other investigators, Darcy and Bazin had made experiments. A few years ago Professor Reynolds, of Owen's College, took this under consideration, and with the remarkable power of interest and experiment which he had shown, he investigated anew the law of resistance and water flowing in channels. He had not only investigated it for himself, but he had re-considered the experiments that were available, especially the experiments of Darcy. In doing so he had plotted the experiments down, but, not only so, he had plotted them down by a system which was not novel, but which was not sufficiently known, namely, instead of plotting the two quantities of which they wished to determine the law of connection, he plotted down the logarithms of those quantities. Professor Reynolds had shown them the law of resistance of water in channels

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was not one law, but that it was trying to get a different formula to cover two portions which were entirely different actions, and which obeyed entirely different laws. He had shown that up to certain velocities the law of resistance was a law of resistance proportionally to velocity. At a certain point that law broke down, and for a short distance there was a somewhat irregular action. At the higher velocity they passed a critical point, and, above that, the law of resistance was changed, being, in the case of very smooth pipes, a variation proportionally to 1·7 power of the velocity, which exactly agreed with experiments made upon the resistance itself, being drawn from water in experiments like Colonel Beaufoy's and others. If that were the case, and he thought it was the case from experiments, and from the investigations of Mr Darcy, the great complication of formulæ lay in trying to make one formula fit two actions, which were different in their nature. Not only had that been shown by the plotting of these experiments, but also by experiments in glass tubes. Up to a considerable velocity, a streak of colour would pass on practically as a mathematical line. Whenever a certain velocity was passed there was no streak seen, and the whole streak of water vanished into a slight colour, which, when viewed by the electric spark, was a number of eddies. The velocity was smooth and steady up to a certain point, and beyond that point it was eddying. It was shown by dividing the connection between the two. They got two laws instead of the complex law, and instead of the other by Professor Weisbach. With regard to the equation on p. 232, as to the flow of water through orifices, the equation which was there given was not the one which most clearly represented the action. Many years ago a number of experiments were made by Mr Francis, and he deduced an empirical formula, in the form of a constant, into the length, minus a certain function of the depth, and the late Professor Thomson, in investigating the matter theoretically, came by distinct and scientific reasoning to exactly the same formula as Mr Francis had come to, after elaborate experiments. He merely mentioned that as being of some interest to those who were engaged in the measurement of quantities.

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Mr GALE said that with regard to the formula for the calculation of water in channels, he had plotted a good many of these curves, and he confessed that both with reference to the observations by Darcy, and also by the earlier observers, the result was highly unsatisfactory. He could not make the plotted curves agree with any formula that he had ever seen or could create, so that he quite agreed that there was something in the motion of water that they did not quite understand. With reference to the discharge over a weir, Professor Barr was quite correct. The length must be taken into account, but in ordinary practice it was scarcely worth while.

The PRESIDENT said that as to the plotting of curves, it would be remembered that a past President, Mr Mansel, used logarithmic ordinates in plotting down the resistance of ships.

On the motion of the President, a hearty vote of thanks was awarded Mr Gale for his paper, and, considering the importance of the subject, it was agreed to adjourn the discussion to opening meeting of next session.

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On "The Drawing Office.

By Mr ARCHIBALD DENNY.

(SEE PLATE XXI.)

Received 13th March, 1895; Read 26th March, 1895.

INTRODUCTION.

IN a shipyard, the drawing office being the fountain head, it is essential that its organisation should be as perfect as possible, and no amount of thought spent upon this problem can be considered wasted or out of place.

This subject has been my constant study for the last thirteen years, and I wish to lay before the members of this society the practical result of that consideration, with the full knowledge that no one man can lay claim to having the best organisation, and with the belief that a thorough discussion on this subject will result in mutual benefit.

GENERAL PLAN.

I append a plan (Fig. 1, Plate XXI.) of the Leven Shipyard Drawing Office; the arrangement has been gradually developed, and is found to answer our purpose extremely well. It will be observed that there are three private offices—one for the chief draughtsman, one for the head of the scientific staff, and a larger room for private designing. Besides these and the main office there is a tracing office, having similarly arranged tables, where 14 young ladies are constantly engaged in tracing the plans designed in the main office.

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There is also a two-storied fireproof building where completed drawings are stored, and this record office, as it is called, is in direct communication with the main office, and will be dealt with later.

Above the main office is the photographic department, reached from the office by a spiral staircase, and fitted with large plate glass windows in the sloping roof facing the south.

The main office has been three times enlarged, lengthwise only. Had it originally been intended to be of the present area, doubtless we would have made it broader and of less length, although the disadvantage of the longer and narrower office is very slight. It would also have been advantageous if the office had had a more lofty ceiling; the present height being only 12 feet.

The tables, of which I show an enlarged sketch (Fig. 2, Plate XXI.), are found most convenient, and I think preferable to the older arrangement of two tressels and a board. The length of the tables is 9 feet; they are supported at three points, and are very rigid; the working boards are laid upon these, or the paper is pinned on them direct, as is found most convenient.

As a rule, the work on plans of excessive length is done on the centre tables, and no inconvenience is felt from the general length of tables being only 9 feet. One table is allotted to each man, except in the scientific department where there are sometimes two to each table. Each man has under the table a convenient private locked drawer.

These tables, while practically rigid, are also easily portable, which is found an advantage in cleaning the office at stated periods.

LIGHTING.

The office is lighted by large windows on either side during the day; this, as the office is narrow, gives good cross light, so that each man works comfortably without shadows. By night the office is artificially lighted with incandescent electric lamps, hung by cords from the ceiling, having counterbalance weights and shades, two being allocated to each table, and each light has a separate switch fitted to the holder.

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These lights are perfectly portable, and can either remain hanging above the board, or be brought down to the work on portable stands. Recently we have introduced lighting on the inverted arc principle; this is found to be a great improvement, the light is well diffused, and practically as good as daylight, and without shadows. The incandescent lamps are, however, retained for the purpose of late work, when only one or two men might be working, the current being supplied from a battery of accummulators.

Since introducing the inverted arcs, we have painted the ceiling pure white and the walls of a very light cream colour. We have further fitted white cotton blinds instead of venetians. We find that these alterations not only improve the comfort of the office but very materially assist the lighting.

HEATING AND VENTILATION.

Good ventilation is essential in a drawing office; this is effected by Tobin tubes acting as air inlets, the inlet being about 7 feet above the level of the floor; the outlets are in the roof, and fitted with Boyle's ventilators.

Heating is by the usual hot water pipes, which pass through long metal cases at the bottom of the Tobin tubes, so that in winter the air is warmed as it enters the room. This system has been successful, the temperature of the office varying little from winter to summer, and the health of the draughtsmen is excellent.

Since the introduction of electric light there has been a marked improvement on the health of the employees, there being a practical absence during the winter of severe colds. This is a point which is sometimes overlooked, but special attention has been drawn to it by Mr Preece of the Post office, and the introduction of electric are light gives not only ozone in the atmosphere, but also prevents large fluctuations in the temperature of the room.

PERSONNEL.

Our drawing office staff numbers 40 males and 14 females, including one clerk, one photographer, one record office keeper, and

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two model makers. The staff is under the command of the chief draughtsman assisted by three heads of departments; the indefinite and deceptive term "leading draughtsman" is not used in our office.

These three heads are responsible in charge of the technical arrangement and scientific departments. The technical department is that in which the design of all the structural part of the vessel is carried out—that is to say, the getting out of the midship section, scantlings, ordering of material and general steel structure of the vessels. I use the general term "steel" instead of iron, as since the introduction of mild steel, sixteen years ago, we have only built eleven iron vessels totaling 21,000 tons, out of 281 vessels totaling 325,000 tons. Iron has now practically disappeared even in the construction of minor details, as not only is the quality detestable—in fact, so bad that it would scarcely stand handling at all—but there is now scarcely any advantage in price, so that steel is now supreme.

The arrangements department is that in which the design of all the remaining part of the constructive work is carried out, namely, the cabin plans, pipe plans, ventilation plans, electric light plans, and details of all description involving the use of wood and other materials apart from the main steel structure.

The third department, the scientific, is that in which all the calculations as to weights, capacities, displacement, stability, speed, trim, etc., are made. In this arrangement I think we depart largely from what is the general rule in other yards, where, I understand, it is usual that each vessel is handed over to one draughtsman, who carries through the whole of the work for that vessel with the assistance of juniors. But we have adopted this arrangement after most careful consideration, and provided the supervision by the chief draughtsman, in the first place, and his assistants, in the second place, is efficient, there need be no clashing of interests, mistakes are less likely to occur, and I believe the work is more economically and expeditiously performed. This is, however, one of those points on which there is not much likelihood of a unanimous opinion for or against, and it is therefore a point on which I need not enlarge further.

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The apprentice question is one requiring consideration not only from the apprentice's but also from the employer's point of view. The old system of making apprentices do nothing but tracing for the first year or two is extinct in our office. Apprentices generally enter from the yard by a competitive examination, and one or two, according to need, enter each year. The examination is of such a nature that they come in well grounded in the elements of naval architecture, mathematics, mechanics, geometrical and freehand drawing. They are at once put to original work, the tracing and mechanical work as far as possible being done by the tracing girls.

Generally, having spent two years in the yard, they are only required to complete their apprenticeship by serving four years in the drawing office. To begin with, one year is spent in each of the three departments, and by that time the bent of the boy's mind and his suitability for any one department is discovered. He completes his fourth year and, if found suitable, remains as a journeyman in the department for which he is found best fitted.

Each apprentice is therefore conversant with the whole work in the drawing office, and they are really useful at a much earlier date than they would be under the old system. They are also encouraged to use the library freely and to continue their studies in the science school in the evening.

Another point of importance is the question of holidays. Salaried officials, which draughtsmen are in our yard, have nothing deducted from their salaries for holidays or a reasonable absence from work through illness.

It is sometimes a little difficult to arrange the holidays to meet the desires of the men and the convenience of the firm. Our rule is, each man has as holidays 18 clear working days; Saturday being counted a half day.

The chief draughtsman keeps a register of all holidays each man takes, and, as far as possible, arranges that about Christmas the men take a week and the balance in midsummer. Odd days are reckoned in, and there is no carrying over from one year to another.

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RECORD OFFICE.

As I have already said, the record office is a two-storied fireproof building. The upper story is in direct communication with and on the same level as the drawing office, access to the lower story being by a spiral staircase. The lower record office is therefore naturally used for storing the plans of vessels which have been completed for some time. The upper office is reserved for the current plans.

Our library is also in this upper office. It contains a large proportion of all books which have been published dealing with our profession, not only in English but also in French and German. The number of volumes at present in the library is 960.

Our draughtsmen have free access to this library, and they are allowed to take the volumes to their homes for private study, under certain strict regulations.

Dealing with plans for vessels in course of construction—each plan, as soon as it is begun, has a suitable title affixed to it, and the letters A., T., or S., indicating which department it belongs to, and by means of a rubber stamp has the necessary reference numbers and other information applied to it at both corners, so that whichever way the plan is rolled up for storing, the information can always be got from the outer end of the plan without unrolling it in any way. A record book is kept by the record office keeper in which all the plans are entered immediately they pass into the record office, and no plan can be removed from the record office without being entered on slates kept for the purpose, and the initials of the draughtsman to whom the plan is handed are recorded on this slate by the keeper. All the plans in the drawing office are removed to the record office every night and re-issued in the morning. This is in case of fire, and as a result of a disastrous fire which occurred in the drawing office of our engineers, Messrs Denny & Co., some years ago, when practically the entire drawings of the firm were destroyed.

With the system described it is possible to get any plan at a moment's notice, and a vast amount of time and trouble is thus saved.

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In the record office there is a case 16 feet by 2 feet 10 inches, divided into 210 dockets, each fitted with a dust-proof door. On these doors there is pasted a card on which is affixed the number of the vessel, the department and a list of the drawings it contains, and it is the duty of the keeper to see that the card is kept up to date, that the drawings are kept in their correct docket, and issued therefrom by himself.

When a vessel is completed a similar separate cardboard docket is used, and into this the plans, after careful revision, are transferred. The record index book is amended to correspond thereto. And this docket is transferred bodily to the lower record office or store, where it is always immediately available.

Detailed plans received from sub-contractors are entered in the index book and kept in a special drawer in cardboard dockets or envelopes. Samples of these dockets and envelopes are here on the table.

One most convenient way for storing plans so that the room occupied shall be a minimum, while the convenience of access is a maximum, is by means of Deacon boxes. Mr Deacon invented this box, and we got the design from Mr Froude.

I have appended a sketch of a box to this paper (Fig. 6), and I have an actual box on the table; this, measuring 9 inches by 17½ inches by 21 inches, can contain 200 speed curves. I think this quite a triumph of compactness. We have fourteen such boxes; the smallest is the one shown on the table, and the largest 11 feet by 3 feet by 1 foot for our deck plans. Of course we only use the boxes for plans which are of recent date and likely to be referred to frequently, the older plans are rolled up and stored in the lower record office.

WORKING ROUTINE.

As soon as the construction of a vessel is commenced, a special passbook is prepared entitled the "History Book." In this book are copied all important letters from the owners, superintendents, or sub-contractors, dealing with details, and also instructions which

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may be given by the partners or manager as to alterations or additions of any description. This we have found absolutely necessary to prevent mistakes or oversights.

When letters come to the counting house which affect the drawing office in any way, they are copied by the typewriter on to sheets gummed along one edge, and sent up to the chief draughtsman with any plans which may have come with them. After looking them over and entering them in the index book of tracings, etc., received and despatched, he hands them to the record office keeper with instructions as to which department they are to be given out to, after being duly stuck in the history books or indexed. In this way nothing can get astray. Any instructions given by the members of the firm or manager to the heads of the departments are entered as soon as possible in the history books, and every morning the chief draughtsman goes over all the history books and enters such notes in the book above referred to. This book is initialed every day by the heads of the departments, so that no note, letter, or plan can be overlooked, and each head knows what is being arranged by the other, and can see that any alterations involved are attended to. This is very necessary, because, while all letters and plans both coming in and going out of the drawing office can be passed through the chief draughtsman, it is impossible to carry this system out in regard to verbal instructions; but, at the same time, it is essential that the chief draughtsman and the heads of the departments should know all that is arranged with the others.

One man in the office is specially charged with the duty of keeping the specifications of vessels up to date. Each foreman and head of department is supplied with a copy of each specification, and should any alteration occur it is the duty of this specification clerk to receive instructions from the chief draughtsman as to the exact terms in which the alteration shall be noted; prepare slips in multiplex, one copy of which is fixed in every specification, including the company's superintendent's specification.

It invariably happens that during the progress of building the yard plans have to be altered, and the foreman must immediately

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know what is done. To meet this, as soon as an alteration is arranged, the draughtsman in charge of the job alters the working plan or plans which are effected to correspond with the office plans, at the same time entering the alteration with date in the "Alteration Book." It is the duty of one of the juniors to keep a duplicate book posted up each day; this latter is kept in the signal cabin in the yard, which is in a central position, and forms a rendezvous for the foremen, and is where a number of the working plans not in immediate use are docketed for convenient reference.

An important question has lately been settled by us, namely, the making of finished plans. With the exception of the plan of lines and the midship section, we now make no finished plans as such—that is to say, we do not make finished plans upon cartridge paper. The plans, as lifted from the vessel and supplied to the owners, are always in great detail, and these are traced from the original pencil plans by the girls, with a special view to their usefulness for photographing. From these as negatives we make the necessary number of plans for owners by the black and white photographic process, and, as is well known to most, these plans when properly made are equal to any finished "inked in" plans. We also make a set of photos for ourselves; these and the original tracings or negatives are docketed so that at any time we can supply duplicates to the owners should they desire them.

CONTROL.

Our yard is unfortunately long and narrow, the distances are therefore great, and the old method of sending messengers to look for foremen and others has been found quite unworkable. We therefore have a private telephone exchange, with twenty stations, and one of these stations is the drawing office.

At the signal cabin already mentioned there is a signal post, 80 feet high, on which a distinguishing signal can be hoisted when any foreman or other official is wanted. They can thus be communicated with from the drawing office with a minimum of disturbance, and are brought much more closely in touch than would otherwise be

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the case. For the same reason, a draughtsman, when obliged to go down the yard, would become practically lost, and if his presence was immediately desired considerable time might elapse before he could be found. There is at the door of the drawing office a slate on which each man on leaving the drawing office to go down the yard enters where he is to be found, and this has also proved most useful.

STANDARDISING.

It is desirable to have as few different sizes of plans as possible for ease in stowing and economy in drawing and tracing paper. Deacon boxes practically control this size for midship sections, deck plans, profiles, and displacement scales, at least one dimension is fixed, namely, the breadth; the other dimension, length, is not so important, but is kept as nearly constant as possible.

We have lately standardised our speed scales, and I show you a sample of this. These will have ears attached to them and be stored in a Deacon box or portfolio. The standard size is 13½ inches by 8¾ inches, and the scales are made upon section paper divided into inches and half inches by sepia lines and into tenths by blue lines. This paper is extremely accurate, and is made by a special ruling machine we have for the purpose in our experimental tank. Side scales are not made, but each curve is marked to show the scale in decimal multiples; it is thus easy to read off from the section paper direct. I think it will be acknowledged that this is a great improvement on the old standard size, namely, 48 inches by 24 inches, which we had and which was generally used. The innumerable side scales were difficult to read, and the whole arrangement was most unhandy.

MISTAKES.

As it is true that mistakes will occur in even the best regulated family, it is equally true that mistakes occur in a well organised drawing office. I have had the desire for some time to institute a mistake book in which would be entered mistakes as they occurred —without, of course, naming the draughtsman who made them—the

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reason for the mistake occurring, and any general notes pertinent thereto.

I would not wish this book in any way to be considered as a black list by the draughtsmen, or that they should think there was any desire to punish them. My desire is that the mistakes which do occur should only occur once, and if this book was properly entered up and divided into suitable sections, I believe it would be of great assistance.

I have found in consulting the draughtsmen that there was no consuming desire to have this book instituted. I think this was through a wrong idea that it was intended as a species of moral pillory. I should be glad to have the opinion of others interested.

PHOTOGRAPHIC DEPARTMENT.

Our photo department is also fairly complete. We use almost exclusively the black and white process; this requires two baths—a gallic acid and a washing bath. Our washing bath is built of wood lined with pewter, and you will observe (see Figs. 1 and 5, Plate XXI.) that by making it of the form shown it can either be used for short and broad or long and narrow plans. We have three frames, one 11 feet 6 inches by 2 feet 7 inches for deck plans, and two 6 feet by 4 feet for short and broad plans. I append sketch of the smaller frames, which, as may be seen, are pivotted and run on wheeled trucks (Fig 4, Plate XXI.). The arrangement for lifting the backs is good, and by having different sized pulleys the inside part is lifted more rapidly than the outside; this not only gives better head room but also conforms to the sloped roof.

The gallic acid or developing bath is quite small, only 6 feet 1 inch by 4 feet 1 inch, and is pivotted at the centre. It can thus be rocked whilst developing so that the liquid is brought in contact with all parts of the paper. The long plans are loosely doubled while being developed and are easily handled. The plans after being developed are drawn over to the washing bath face up and washed by means of a hose and rose.

In scheming out these arrangements we were assisted by the

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experience of our friends Messrs J. & G. Thomson and Messrs Denny & Co.

Last year 2700 separate photographs were made in the department by one man.

CONCLUSION.

In conclusion, I end as I began, by saying that I think it impossible to spend too much time and thought upon the organising of the drawing office.

In 1868 our drawing office staff consisted of 7 men including the model-maker, an important man in these days; the foremen got mere general plans and were allowed to scheme out their work as best they might. Now-a-days all that is changed, and I believe for the better as a whole; plans are very detailed, carefully thought out, and much increased in number.* This is necessary, partly because of the now complex nature of modern vessels, but really induced by a desire to see the end from the beginning, to avoid mistakes and changes, and also with a view to more rapid and cheaper production. This is really the key-note—cheapness of production; and while the drawing office expenses are enormously increased, I believe that every pound spent judiciously in the drawing office saves two or three in the yard.

The discussion of this paper took place on 30th April, 1895.

Mr W. D. ARCHER said that he had nothing to say by way of criticism, but it would be a pity that this paper should go past without their thanks. It was not a show paper, but it must have given Mr Denny some trouble to get it up, and there was good solid information in it. He had been a draughtsman himself, and had worked in an office not so well heated and lighted as this one; and he remembered the very distinct difference that they felt when they had the electric light introduced into the office instead of gas. If

* Last year we issued 3694 plans to the yard, owners, sub-contractors, and others.

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they wanted to get good work out of people they had to make them tolerably comfortable. He thought that Mr Denny had done a service in showing what a drawing office ought to be.

The PRESIDENT said that Mr Denny's paper did not admit of any difference of opinion, and he thanked him in their name for it.

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"*A New Departure in Steam Engine Economy, with a Description and Tests of Field's Combined Steam and Hot Air Engine.*"

By Professor ANDREW JAMIESON, M.Inst.C.E., F.R.S.E., etc.,
Of the Glasgow and West of Scotland Technical College.

Read 30th April, 1895.

ANY new means of economising coal or steam is always welcome before this Institution if it be practicable and applicable to the daily requirements of the engineer and manufacturer. Consequently, I have much pleasure in placing before the members a description of a "New Departure in Steam Engine Economy," along with the detailed results of the tests, which I was privileged recently to obtain during a two days' trial of Field's combined steam and hot air engine.

I do so entirely with the view of stimulating a discussion on this most important subject.

GENERAL DESCRIPTION.

This invention is, I understand, the joint design of Mr Edward Field, M.Inst.M.E. (inventor of Field's well known tubular boiler), and Mr F. Saunders Morris, M.Inst.M.E., working in conjunction with Messrs Musgrave & Co., of Bolton, and Mr George Dixon, their chief engineer.

It consists of a hot air pipe connection to the jacket and to each end of a single cylinder non-condensing engine.

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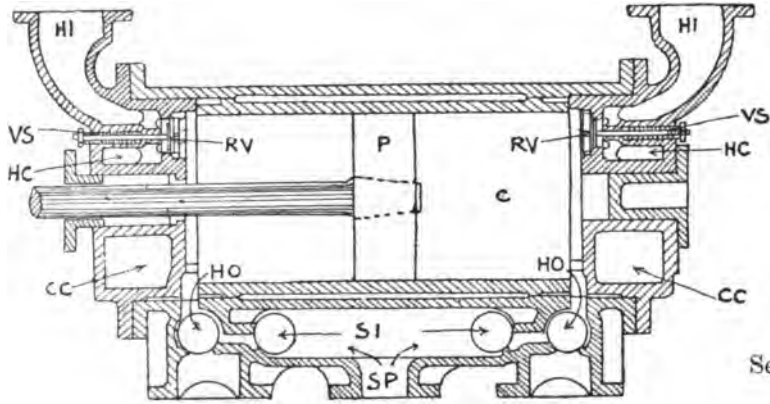
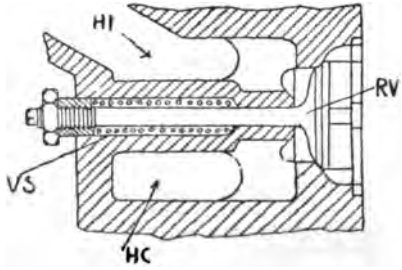
Fig. 1.—Field combined Steam and Hot Air Engine.

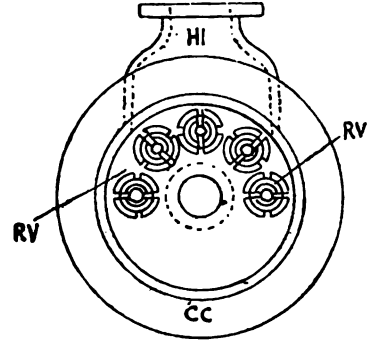
Sectional elevation of cylinder.





Enlarged section valve.

Front end view.



Section of the M.P. cylinder.

Index to parts—

SP	represents	steam pipe
SI	,,	steam inlets
C	,,	cylinder
CC	,,	cylinder covers
P	,,	piston
HI	,,	hot air inlets
HC	,,	hot air chest
HO	,,	hot air and steam outlets
RV	,,	regulating valves
VS	,,	valve springs

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A Roots blower, driven by the engine, draws fresh cold air from the engine room, and forces the same through a series of heating pipes placed in the main flue between the boiler or boilers and the chimney. This heater, therefore, occupies pretty much the same position as a Green's economiser. The air was maintained, in my experiments, at a mean pressure of $1\frac{3}{4}$ lbs. on the square inch, and delivered to the ends of the cylinder at a mean temperature of 553 degrees Fah., and to the valve-casing jacket at about 380 degrees Fah. This hot air was admitted to the cylinder through special cylinder covers, each containing five inlet valves, which automatically opened inwards as soon as the exhaust steam commenced to escape. These valves continued open until compression commenced, being held close to their seats by light spiral springs, all as shown in Fig 1. Consequently, the whole internal surface of the cylinder was heated up to a temperature far exceeding that of the steam, thus preventing the possibility of condensation taking place within the cylinder. Under these circumstances, I got the excellent result of 18·6 lbs. of steam per I.H.P.-hour from a single cylinder non-condensing engine—a result which, as far as I can learn, has never been equalled by any other method of using steam in a single cylinder, and without subsequent condensation.

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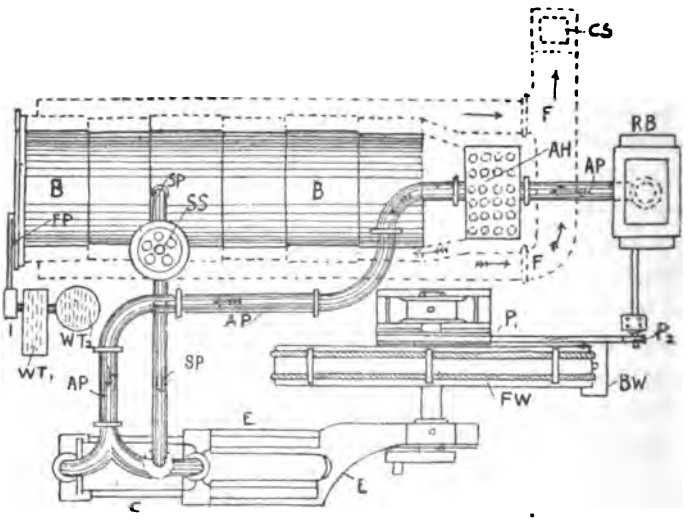
ARRANGEMENT OF PLANT AND METHOD OF TAKING THE TESTS.

Boiler and Coals.—From the following figure and index to parts you will at once see how the plant was arranged.

Fig. 2.



GENERAL ARRANGEMENT OF PLANT FOR TESTING THE FIELD ENGINE.

Index to parts—

B	represents	boiler	WT_1WT_2	represents	water tanks
F	„	flue	SS	„	steam superheater
CS	„	chimney stalk	SP	„	steam pipe
AH	„	air heater	E	„	engine
RB	„	Roots blower	C	„	cylinder
AP	„	air pipes	FW	„	fly wheel
FP	„	feed (water) pipe	BW	„	brake weights
I	„	injector	P_1P_2	„	pulleys with belting for driving RB

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Instead of one boiler, however, there were two simple Cornish boilers, which delivered their waste gases into a chimney of only 40 feet in height. This height is by far too short to give a good draught, but as we were not specially studying the economy of the boilers as steam generators, I will not put any stress on the coal burned per pound of water evaporated, but rather on the steam used per horse power-hour. The coal used, was, however, weighed very carefully, and the fires were left in as nearly as possible the same condition at the end of each trial as at the beginning.

Feed Water and its Apparatus.—The feed water used was accurately accounted for by the system of water tanks and gauges. At the instant of commencing each day's trial, the height of the water in each boiler gauge glass was noted, and marked by a string; and the water tanks WT_1 and WT_2 were at the same time filled up to definite marks. An injector drew water from WT_1 as required, down to a certain mark each time and fed the same into the boilers. Then WT_1 was filled to its upper mark from WT_2. Whenever the water in WT_2 had fallen to a zero mark, it was refilled to the upper mark. The weight of the contents of the tank WT_2 (between the zero and upper marks), was found to be exactly 1000 lbs. This result was checked both by measurement and calculation.

Care was taken that the heights of the water in both boilers and in the water tanks were identical, at the end of each day's trials, with that at the beginning thereof. The total weight of water used was then calculated from the number of times WT_2 had been filled, minus the water caught from all leaks and traps, which was also very carefully weighed.

The Engine.—Steam was kept as steady as possible at an average pressure of 113 lbs. on the square inch, and was supplied very dry from the super-heater to a Corliss engine, made by Messrs Musgrave & Co. There was nothing special about this engine except the application of Field's arrangement; in fact, the engine had not a high mechanical efficiency, since the ratio of its B.H.P. to its I.H.P.

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had been found by Professor Kennedy to be only about 83 per cent. It then used 31 lbs. of steam per I.H.P.-hour when developing nearly the same power as in my first day's test, *i.e.*, with a medium or normal load.

Thermometers and Hot Air Pressure Gauge.—Four accurate high temperature thermometers were used to ascertain the temperature of the hot air—one where the air entered, another where it left the valve casing jacket, and one in each cylinder cover. A fifth thermometer was placed where the cold air entered the Root's blower, and another in the feed water tank WT_2. The pressure of the air as it came from the heater was indicated by a Bourdon pressure gauge.

Indicators.—Two kinds of indicators were used, the Crosby and the Wayne. This latter instrument has recently been brought out by Messrs Elliott Bros., of London, and I have now the pleasure of showing it to you as well as of illustrating it by Fig. 3. Specimens of the indicator cards taken with this instrument for both the normal load and the very light load—really about quarter of full power—are given, and they demand special attention from their unusual shape.*

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* For a description of the Wayne indicator see Author's text book on "Steam and Steam Engines," tenth edition, page 429.

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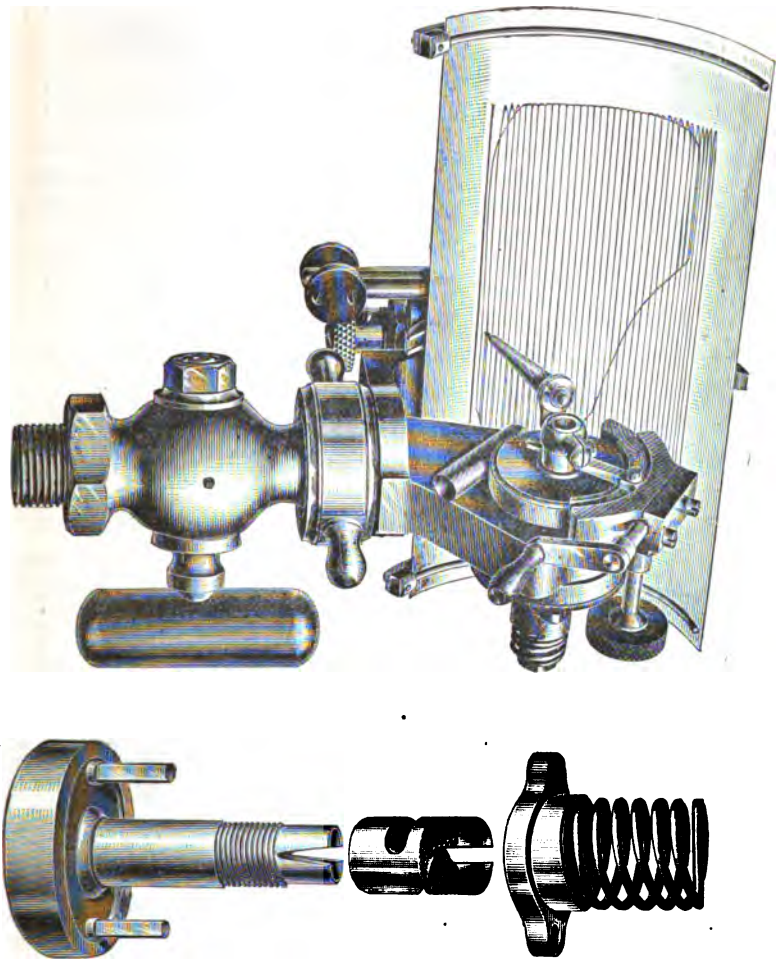

Fig. 3.—The Wayne Steam Engine Indicator as arranged for taking Line Diagrams.

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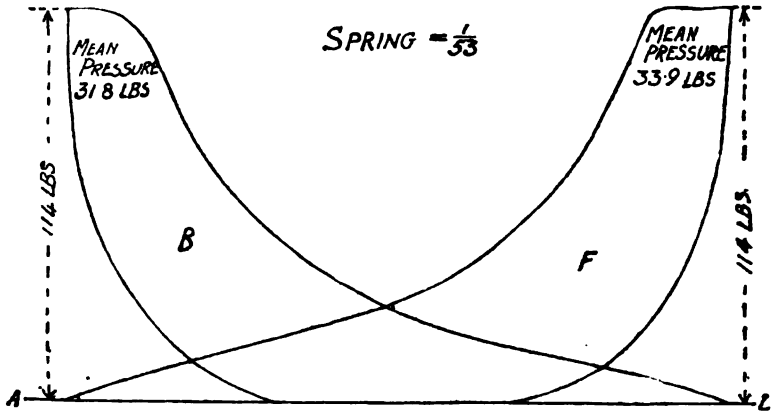

Fig. 4.—Full size indicator diagrams, taken by Prof. Jamieson with the Wayne indicator from Field's combined steam and hot air engine, at medium power, November 30th, 1894.

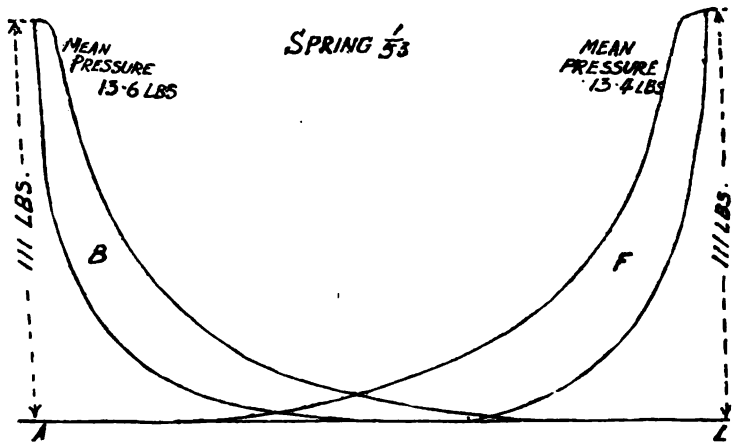

Fig. 5.—Full size indicator diagram, taken by Prof. Jamieson with the Wayne indicator from Field's combined steam and hot air engine, at quarter power, December 1st, 1894.

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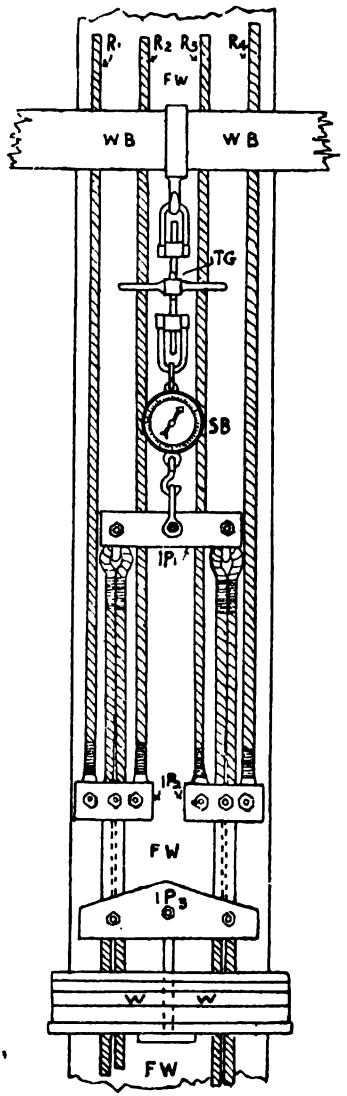
Brake Gear.—The large fly-wheel, of fully fifty feet in circumference and twenty inches in width, was used as a brake wheel.

Fig. 6.—End View of Brake Gear.



Index to parts—

FW	represents	fly-wheel
R_1 to R_4	„	ropes
WB	„	wooden beam
TG	„	tightening gear
SB	„	spring balance
$IP_{1,2,3}$	„	iron plates
W	„	weights

This fly-wheel was encircled by four parts of a strong and flexible rope, one inch in diameter. The inner ends of this rope were attached to a spring balance, tightening gear, and wooden beam, while the outer ends were connected to a fixed weight, consisting of nearly 1000 lbs. of cast-iron for the first day's trial, and about one-third of that for the second day's run.

In other words, the dynamometer was an excellent and large example of what has now come to be termed the "Society of Arts Brake." It worked perfectly, and there was no undue heating anywhere. This was no doubt owing partly to the stream of water which played on the inside of the ⌊‾⌋ shaped fly-wheel, to the large surface, and to the

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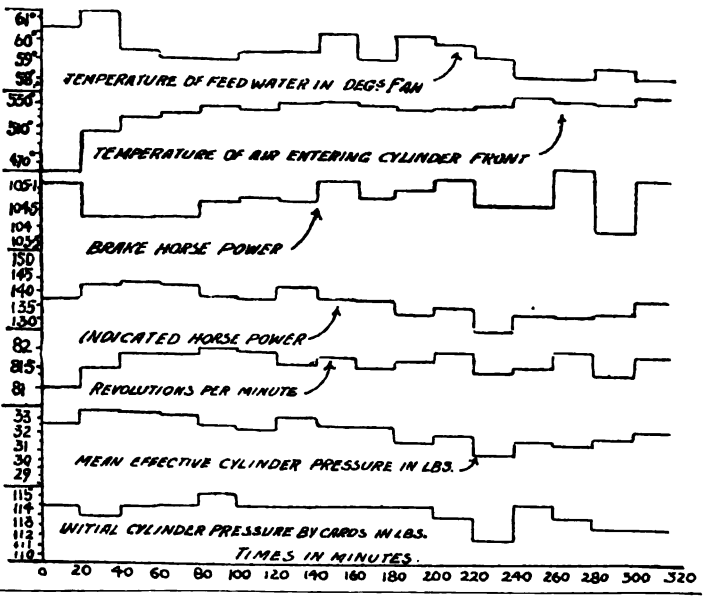
strong draught caused by the fan action of the wheel. As far as possible, however, no water was permitted to get between the rope and the fly-wheel.

Counter.—The number of strokes and revolutious per minute were obtained by aid of a Harding's counter fixed to the crank shaft.

TESTS AND RESULTS.

With the aid of several assistants,* I was enabled not only to check all the permanent data, such as dimensions and weights, but also to get simultaneous observations every twenty minutes of each of the items numbered in the following tables, with the exception of the indicator cards, which were, however, taken as soon after the steam gauge readings as possible. The more important items in the first day's run of five continuous hours are also shown graphically in Fig. 7.

Fig. 7.


TEMPERATURE OF FEED WATER IN DEGS FAH
TEMPERATURE OF AIR ENTERING CYLINDER FRONT
BRAKE HORSE POWER
INDICATED HORSE POWER
REVOLUTIONS PER MINUTE
MEAN EFFECTIVE CYLINDER PRESSURE IN LBS.
INITIAL CYLINDER PRESSURE BY CARDS IN LBS.
TIMES IN MINUTES.
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320

* I have specially to [thank Mr William Murray Morrison and Mr Davenport for their active and efficient assistance.

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I have not tabulated the second day's trial so fully as that of the first, but the more important results are given in the summary or last table, along with those extracted from the first day's trial. On the second day, each successive observation agreed so very exactly that I did not think it worth while running for a longer time than 3 hours 20 minutes, more especially as it was a very light load. In fact, the pressure of the steam, the speed, and the power of the engine, etc., repeated themselves almost like clock-work, throughout each of the trials.

Summary of the principal results of Professor Jamieson's tests on the Field steam and hot air engine:—

1	Date of tests, - - -	Nov. 30th,/94	Dec. 1st,/94
2	Duration of trials, - -	5 hours	3 hours 20 m.
3	Mean cross area of cylinder, -	280·8 sq. ins.	280·8 sq. ins.
4	Length of stroke, - -	2·997 feet	2·997 feet
5	Mean revolutions per minute,	81·66	82·23
6	Mean boiler pressure by gauge,	113·4 lbs.	113·1 lbs.
7	Mean initial cylinder pressure by indicator cards, - -	113·4 lbs.	110·7 lbs.
8	Terminal pressure by indicator cards, - - - -	0 lbs.	0 lbs.
9	Mean effective cylinder pressure,	32 lbs.	13·4 lbs.
10	Mean pressure of hot air supply,	1·74 lbs.	1·8 lbs.
11	Mean temperature of hot air supply to inside of cylinder,	553 deg. Fah.	530 deg. Fah.
12	Mean indicated horse power,	136·75	57·6
13	Mean effective brake pull, -	840 lbs.	259 lbs.
14	Mean brake horse power, -	104·6	32·5
15	Mechanical efficiency $= \frac{\text{brake horse power,}}{\text{indic'd horse power,}}$	76·5 per cent.	67·6 per cent.
16	Steam per I.H.P.-hour, - -	18·6 lbs.	21·4 lbs.
17	Steam per B.H.P.-hour, - -	24·26 lbs.	37·9 lbs.
18	Coal per I.H.P.-hour, - -	2·45 lbs.	3·2 lbs.
19	Coal per B.H.P.-hour, - -	3·21 lbs.	5·68 lbs
20	Mean temperature of feed water,	59 deg. Fah.	60·8 deg. Fah.
21	Feed water per lb. of coal, -	7·5 lbs.	6·6 lbs.
22	Feed water per lb. of coal reduced to 212 degrees Fah., -	8·9 lbs.	7·9 lbs.
23	Factor of evaporation, - -	1·19	1·2

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APPLICATION AND EASE OF CONVERTING ENGINES INTO FIELD'S SYSTEM.

The several alterations which had to be made on the original engine, in order to convert it into Field's system, were very simple, as they merely consisted in putting on new covers with hot air inlet valves and hot air pipe attachments, as shown and indexed for Figs. 1 and 2. The steam admission and exhaust valves, as well as the valve gear, remained untouched. Consequently, in the case of single or double cylinder non-condensing engines, with covers at each end of their cylinders; as well as in the case of all new engines of that type, including even locomotives, there should not be any practical difficulty in its application.

LOSS OF POWER DUE TO DRIVING ROOT'S BLOWER AND HEATING THE AIR.

I understand that Professor Kennedy estimated from his tests of this same engine, both before and after its conversion into Field's system, and under similar conditions of load, etc., that about 5 per cent. of the I.H.P. was absorbed in driving the Root's blower; but that the heating of the air in the pipes placed in the boiler flue, did not appreciably diminish the efficiency of the boilers or raise the coal bill per unit of water converted into steam. * As I had only an opportunity of testing the engine after conversion I accept Professor Kennedy's first results, and on comparing them with my first day's test I find that the Root's blower lowered the mechanical efficiency of the engine by about 6 per cent. This, then, is the price paid for obtaining the greater economy of steam used in the cylinder, which works out to be a clear saving of 40 per cent., for:—

$$\left.\begin{array}{c}\text{Steam used}\\ \text{per I.H.P.-hour}\\ \textit{before}\text{ conversion}\\ 31\text{ lbs.}\end{array}\right\} : \left\{\begin{array}{c}\text{Steam used}\\ \text{per I.H.P.-hour}\\ \textit{after}\text{ conversion}\\ 18{\cdot}6\text{ lbs.}\end{array}\right\} :: 100 : x$$

$$\therefore x = 60$$

Or, 100 — 60 = 40 per cent. gain.

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HIGH EFFICIENCY AT LOW LOADS.

I should like to call special attention to item 16 in the last table of the summary of results for the two days' tests. It is there stated that the pounds of steam per I.H.P.-hour are 18·6 for medium power and only 21·4 for quarter power or a very light load. This is, therefore, one of the most gratifying features of the invention, namely, that the consumption of steam increases so very slowly compared to the decrease in the I.H.P. The large amount of power absorbed by the engine itself and by the blower, no doubt causes the consumpt of steam per B.H.P.-hour to increase apparently more in keeping with that of other non-condensing engines (namely from 24·26 to 37·9 lbs.); but, with a more efficient engine and blower this consumpt would certainly have appeared so very much less than that of any case known to the author of a single cylinder non-condensing engine, that he fancies many will be willing to give Field's system "a fair field if no favour."

The PRESIDENT said that it would be rather difficult for the meeting to discuss this paper, inasmuch as they had not seen it in type, and Professor Jamieson had been compelled to give merely a summary of it on account of the large amount of work before the Institution that evening.

Mr CLEGHORN said that they could hardly allow this paper to pass without taking notice of it, as it described a new departure in steam engineering. As the President had remarked, the system described was not altogether applicable to condensing engines, but he understood Professor Jamieson to say that in addition to hot air being admitted to the cylinder at release, the cylinder itself was surrounded by a hot air jacket. This latter provision contributed greatly to economy in steam consumed by the engine. He thought that this feature of the system could be applied with great benefit to condensing engines, specially to marine engines, where part of the heated gases from the uptakes could be led, by a light casing,

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round the cylinders, instead of escaping direct to the atmosphere b
the funnel. Perhaps marine engineers and shipowners would b
unwilling to adopt such a system till they were fully convinced o
the low efficiency, through initial condensation, of engines as no
constructed. He would instance the slow running single cylinde
condensing engine sometimes fitted in paddle steamers, where initi
condensation would amount to 40 or 50 per cent. of the wate
evaporated by the boiler. He thought it was a pity when th
Research Committee of the Institution of Mechanical Engineer
were investigating the efficiency of marine engines that they did no
try a paddle boat having a single cylinder condensing engine. Th
compound condensing engine of the "Ville de Douvre" was trie
with fair success, but he thought they should have come to th
Clyde and had a trial of one of the single cylinder condensing
engines. He believed that the companies owning vessels fitte
with this type of engine would reap benefits by submitting them t
a scientific trial, for they would find it advisable, in future engines
to adopt means in order to lessen the initial condensation, and thu
they would effect a double saving, namely, in a diminished coa
consumption and in a reduced initial cost, since so large, and there-
fore so heavy, boilers were no longer necessary. He did not forge
that a number of different conditions combined to determine the
most profitable type of machinery for the vessels, but just on that
account was a reliable trial of this class of engine all the more
necessary. Might he therefore suggest that this Institution take up
this matter, and doubtless their honoured President could help them
by getting some of the companies owning such engines to make
trials under the presidency of Professor Jamieson, who was an able
experimenter. He had much pleasure in thanking Professor
Jamieson for his paper.

Mr F. J. ROWAN said that he noticed in the table of figures,
which had been handed round, that the air introduced into the
cylinders was heated some 400 degrees Fah. or more.

Professor JAMIESON—550.

Mr F. J. ROWAN said he would like to ask Professor Jamieson if

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squar
3,000
nk (2
eight

a at front end = 276 square
cumference of circle (whose
es = 2. (15) Area of each
feed water tank, from mark

ater Supply.

9	28	
I.P.	REMARKS.	
37·5	circumference of the centre line of	
31·6	ke load rope was taken as = 50·3 ft.	
31·9	of 50·8 ft. (the size used on previous	
31·2	This reduces the mechanical effi-	
38·1	about 1%. By the end of the five	
37·2	est 81 lbs. of water had been drained	
30·4	he steam pipe, and 10 lbs. from the	
7·7	blow-off cock of No. 1 boiler. Thus	
7·4	91 lbs. to be deducted from the	
3·6	lbs.; the total feed water used, or a	
5·6	nsumption of 2,537·8 lbs. per hour.	
9·0	the five hours' test 1,680 lbs. of coal	
3·5	urned, thus making the consump-	
3·0	coal per I.H.P. hour = $\frac{1,680}{5 \times 136·75}$	
3·5	lbs., and per B.H.P. hour = $\frac{1,680}{5 \times 104·6}$	
6·8	lbs.	
3·75		

The mean weight of feed water

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häffer

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he had ascertained what was the lowest amount of heating required to produce economical results, because it seemed to him that the result shown in his table meant that a good deal of heat which ought to be usefully employed in the boilers had been primarily wasted, and was merely arrested by this new device. Perhaps it would be better to have a comparison with an engine and boiler utilising the heat in the proper way to begin with. If there was not so much waste heat in the escaping gases, the question was, would there be anything like the economy produced in an engine of this kind?

Mr W. CARLILE WALLACE said that putting air into a cylinder at that high temperature might have an injurious effect on the walls of the cylinder, and he would be glad to know what was Professor Jamieson's experience in regard to this.

Professor JAMIESON said, in answer to the first speaker, that he would be very glad to take a hand in any set of trials of the boilers and engines of old paddle boats if the proposal was accepted and thoroughly thought out by a recognised committee. No bad effects were observable on the lining of the cylinder or on the skin of the piston rod from the combined hot air and steam, up to and including the date of his tests. The temperature of the waste gases entering the chimney might reach 600 degrees Fah.

Mr ROWAN asked if the hot waste boiler gases going to the chimney were much lessened in temperature when the air heater was employed?

Professor JAMIESON said no; very little indeed.

Mr ROWAN said he thought that there was a frightful excess of heat being wasted!

Professor JAMIESON said that he had not had an opportunity of personally testing the temperatures of the waste furnace gases with and without the air heater in circuit, but he understood that Professor Kennedy had done so and had found very little difference. The reason for this would be apparent when they considered that the specific heat and specific gravity of air were so very small. By calculation it might be proved that about 20 lbs. of air per minute were

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heated from 60 degrees to 550 degrees Fah. and forced into the engine cylinder. This was equivalent to an expenditure of 2180 British thermal units, or the conversion of less than $2\frac{1}{2}$ lbs. of water into steam per minute from and at 212 degrees Fah., or steam equivalent to one-eighth of a horse power.* Even supposing that the heat units absorbed by the air were double this amount, it is quite inappreciable with such a large plant. Of course, the power taken up in driving the Root's blower was far in excess of this quantity. In fact, it was the chief factor to consider in comparing the efficiency of the engine before and after conversion into Field's system. Whether

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* *Data.*—Revolutions per minute - = 81
Cross area of cylinder - = 280 sq. ins.
Stroke of piston - - = 3 feet.
Initial temperature of air (say) = 60 degrees F.
Final temperature of air (say) = 550 degrees F.
Pressure of air (at cylinder) say = 1 lb. per sq. in.
Assume that cylinder is half full of air and half full of steam each time,

Then volume of air required per minute = $\frac{1}{2}$ volume of cylinder × number of strokes per minute,

$$\frac{1}{2} \times \frac{280}{144} \times 3 \times 2 \times 81 = \frac{945}{2} = 472{\cdot}5 \text{ cubic feet.}$$

But, 1 cubic foot of air at 60 degrees F. and atmospheric pressure (15 lbs. absolute) weighs $\frac{1}{13}$ lb.

Therefore, 1 cubic foot of air at 550 degrees F., at 1 lb. pressure, weighs

$$\frac{1}{13} \times \frac{460 + 60}{460 + 550} \times \frac{1 + 15}{15} \text{ lb.} = \frac{1}{13} \times \frac{4}{1010} \times \frac{16}{15} = \frac{64}{1515} \text{ lb.}$$

Therefore, 472·5 cubic feet of air, at 550 degrees F., and 1 lb. pressure, weigh

$$\frac{64}{1515} \times 472{\cdot}5 = \frac{2016}{101} = 20 \text{ lbs.,}$$

Therefore weight of air required per minute = 20 lbs.

Heat required per minute to heat air from 60 to 550 degrees Fah.

$$= 20 \times {\cdot}238 \times (550 - 60)$$
$$= 4{\cdot}76 \times 490$$
$$= 2332{\cdot}4 \text{ B.T.V.}$$

This is equivalent to evaporating x lbs. of water at 212 degrees Fah. to steam at 212 degrees Fah. where

$$x = \frac{2332{\cdot}5}{966}$$
$$x = 2{\cdot}4 \text{ lbs.}$$

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this invention met with popular favour or not, he was certain that they would all recognise in it, a very ingenious means of overcoming the initial condensation of steam at a comparatively small working cost, and at little prime cost and trouble in suitable cases.

The PRESIDENT said that they must thank Professor Jamieson for his paper. It would be printed in complete form, and the discussion could be continued next session. He had no doubt that some additional questions might arise before that time. He had some difficulty for his own part on one point. If the air which was put into the cylinder did not lower the temperature of the uptake, he did not see where the heat came from. That, and perhaps some other obscurities, might be elucidated in the month of October. With regard to the experiments proposed by the first speaker, no doubt he alluded to the engines which were in common use in Clyde river steamers, and he must say that he had to plead guilty to being concerned at the present moment in the construction of one. It was not because they thought it was an economical engine in the using of steam that that form of engine was decided upon. He thought it had been established that the single engine could not compete with the compound engine, much less with the triple expansion, but there was something else than the economy of coal to be considered. On the Clyde, the steamers were running almost from the pit mouth, and as they had to pay depreciation and insurance for twelve months in about 100 days running, the question of first cost became a most important one, and economy of fuel was really of secondary consideration. Owners of steamboats on the Firth of Clyde might prefer to spend the money in coal rather than in elaborate and heavy machinery requiring a large vessel to carry it. He was not sure that the balance of economy could be found on the side of what was really the more advanced form of engine, but at all events those owners and managers who preferred to adopt the simple engine, did so in the full knowledge of the advantages of compound and triple engines.

The further discussion of this paper was then adjourned to opening meeting of next session.

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Annual General Meeting, 30th April, 1895.

Annual Financial Statement.

Mr JAMES M. GALE submitted the Annual Financial Statement, and stated that the accounts had all been audited. The funds of the Institution had increased upon the whole during the past year by about £240, and the money in bank in General Fund Account had increased by £142. That was very gratifying, and the Council should now be in a position to deal in a liberal manner with Mr Barr or his successor with regard to the library.

The Statement was adopted, and, on the motion of the PRESIDENT, a vote of thanks was given to the Auditors, Messrs Peter Stewart and W. A. Charlton.

Election of Office-Bearers.

The PRESIDENT stated that it now became the duty of the Institution to elect a President for the next two sessions. It was of course competent to that meeting to propose any gentleman they might think proper for President, but it had been the custom for the Council to consider this matter beforehand, and make a recommendation which could either be adopted or not, as the meeting thought proper. The Council proposed the name of Sir William Arrol—a gentleman very well known throughout the country for his great achievements in practical engineering. It was quite superfluous to say anything in favour of that proposition. The Council had reason to believe that Sir William would accept the office, if the Institution decided to elect him.

Mr CHARLES P. HOGG seconded the nomination of Sir William Arrol as President, which was unanimously agreed to.

Mr JAMES MOLLISON proposed Professor Andrew Jamieson for

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the vacant office of Vice-President. Professor Jamieson had contributed some very valuable papers to the Institution, and had all along taken a very great interest in its affairs.

On being seconded by Mr GALE, Professor Jamieson was elected for the vacant Vice-Presidentship.

The PRESIDENT then stated that it became their duty to elect six Councillors in place of the five gentlemen who retired, and in place of Mr Lindsay Burnet, whose loss they deplored.

Several names having been duly proposed and seconded, a ballot showed that the following gentlemen had been elected as Councillors—Messrs Sinclair Couper, James Denny, George Russell, John Duncan, Robert Caird, and William Foulis.

Mr James M. Gale was unanimously re-elected Hon. Treasurer.

Premiums of Books were awarded to Mr William Arnot and to Mr Alexander Morton for papers read Session 1893-94.

Mr GALE said that this was the last occasion in which their President, Mr Inglis, would occupy the chair, and, after the great skill he had displayed, and the labour he had taken during his presidency, the least they could do was to give him a very hearty vote of thanks.

The PRESIDENT said he was exceedingly obliged for the kind expressions that Mr Gale had used, and which they had so kindly endorsed. He was only too conscious of his shortcomings (cries of "No, no"), but if his conduct in the chair had not been in accordance with their expectations or his own desires, he had done his best, and the best could do no more. He had learnt many things during his tenure of office, and one of them was a very wholesome respect for the abilities, knowledge, and experience possessed by members of this Institution. He could not help saying that he thought a larger proportion than was desirable of these qualities was in what might be called a latent condition. He hoped that under the new President more than heretofore of their dormant

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energy would be converted into useful work. The Council had been considering some alterations in their procedure which ought to have a good effect, and he was sure the members would second the Council in any changes which might be for the benefit of the Institution. One suggestion which Professor Barr made was the earlier printing of papers, to the end that their discussions might be more complete and more interesting than under the old system. In that respect they were behind other and kindred societies. There was no practical difficulty that he could see in carrying out this reform, and it was not too late to mend. He need not enlarge on that topic, but these things would be taken up by the new Council. He thanked them all for the unfailing courtesy and consideration which had been extended to him during the past two sessions.

The vote of thanks was heartily accorded.

The JAMES WATT ANNIVERSARY DINNER was held on Saturday, the 19th January, 1895, in the Windsor Hotel, Glasgow,

Mr JOHN INGLIS, President, in the Chair.

There was a large and influential attendance of members and distinguished guests.

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Institution of Engineers and Shipbuilders
IN SCOTLAND
(INCORPORATED).

THIRTY-EIGHTH SESSION, 1894-95.

MINUTES OF PROCEEDINGS.

THE FIRST GENERAL MEETING of the THIRTY-EIGHTH SESSION of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 23rd October, 1894, at 8 P.M.

Mr JOHN INGLIS, President, in the Chair.

The Minute of Annual General Meeting of 24th April, 1894, was read and approved, and signed by the President.

The PRESIDENT delivered his Introductory Address. On the motion of Mr GEORGE RUSSELL, Vice-President, a hearty vote of thanks was awarded the President for his Address.

A paper on "The Construction and Use of Pressure Gauges," by Mr C. R. L. LEMKES, was read. The discussion was adjourned to next General Meeting.

The awards made at Annual General Meeting of 24th April, 1894, were presented, viz. :—

The Marine Engineering Medal to Mr SINCLAIR COUPER for his paper on "The Return Tubular Marine Boiler for High Pressures."

And Premiums of Books

To Mr W. CARLILE WALLACE for his paper on "Some Causes of Failure in Tunnel Shafting."

To Mr JOHN BARR for his paper on "Testing Machinery and Electric Water Level Recording Apparatus." And

To Mr E. G. CAREY for his paper on "The Bridges of the Manchester Ship Canal."

The formal delivery to Mr CAREY of his award could not be made until another meeting; the volume selected being not yet completed.

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THE SECOND GENERAL MEETING of the THIRTY-EIGHTH SESSION of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 20th November, 1894, at 8 P.M.

Mr GEORGE RUSSELL, Vice-President, in the Chair.

The Minute of General Meeting of 23rd October, 1894, was read and approved, and signed by the Chairman.

The discussion of paper on "The Construction and Use of Pressure Gauges," by Mr C. R. L. LEMKES, was proceeded with and terminated, and a vote of thanks awarded Mr Lemkes.

A paper on "The Witwatersrand Gold Field," by Mr ROBERT T. MOORE, B.Sc., C.E., was read. The discussion was deferred till next General Meeting.

The Chairman intimated that the Candidates balloted for had been unanimously elected, the names of these gentlemen being as follows:—

AS MEMBERS:—

Mr THOMAS ARROL, Jun., Mechanical Engineer, 101 Armadale St.
Mr ANDREW GILLESPIE, Mechanical Engineer, 34 St. Enoch Square.
Mr ARCHIBALD KERR, Mechanical Engineer, 2 Kelvinside Gardens.
Mr JOHN MACPHERSON, Marine Engineer, 5 Holland Place.
Mr SAM MAVOR, Electrical Engineer, 3 Elmbank Crescent.
Mr A. R. PATON, Mechanical Engineer, Redthorn, Partick, and
Mr GEORGE THOMSON, 35 Marchmont Crescent, Edinburgh.

AS GRADUATES:—

Mr ROBERT BOWIE, Apprentice C. and M.E., 156 St. Vincent Street.
Mr JAMES CRAIG, Apprentice Civil Engineer, 14 Bridge Street.
Mr ARCHIBALD BENJAMIN IRVINE, Apprentice Engineer, 3 Newton Terrace.
Mr FREDERICK W. L. HEPTING, Apprentice Engineer, 14 Dumbarton Road.
Mr JOHN KIRK, Marine Draughtsman, 4 Minard Ter., Partickhill.
Mr JOHN SIMPSON MILLAR, Student Mechanical Engineer, 3 Beaconsfield Street, Partick.
Mr JOHN MAITLAND, Marine Draughtsman, 53 Bentinck Street.

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Mr ROBERT D. MACKINTOSH, Mechanical Draughtsman, Bellevue Place, Garngad Hill.

Mr ALLAN STEVENSON, Apprentice Mechanical Engineer, 69 Cadder Street, Pollokshields, E.

Mr WALTER M. THOMSON, Mechanical Engineering Draughtsman, Bellevue, Clydesdale Street, Hamilton.

Mr JAMES THOMSON, Mechanical Engineering Draughtsman, Bellevue, Clydesdale Street, Hamilton.

Mr JOHN WALKER, Student Mechanical Engineer, Ferncliffe, Old Cathcart.

THE THIRD GENERAL MEETING of the THIRTY-EIGHTH SESSION of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 18th December, 1894, at 8 P.M.

Mr JOHN INGLIS, President, in the Chair.

The Minute of General Meeting of 20th November, 1894, was read and approved, and signed by the President.

The alteration of No. 10 of the Library Bye-Laws, as proposed by the Council, was considered.

Professor BARR moved that the alteration be adopted, and that the part of Bye-Law No. 10 affected by this alteration should read:—"Books shall not be lent to any persons except Members, Associates, or Graduates of the Institution, or Members of kindred Institutions to whom the Council may grant the privilege, upon such terms as the Council may from time to time determine."

This was seconded by Mr JAMES MOLLISON, and was unanimously agreed to.

There being no remarks upon the paper by Mr ROBERT T. MOORE, on "The Witwatersrand Gold Field," this part of the business was terminated, and a vote of thanks awarded Mr Moore for his paper.

A paper on "A New Mining Motor," by Mr HENRY A. MAVOR,

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was read. A discussion followed, and was continued to next General Meeting.

Mr GEORGE CARRUTHERS THOMSON gave an abstract of his paper on "Results of Evaporative Tests on Land Boilers," the discussion being deferred until the publication of the paper in complete form.

The Chairman intimated that the Candidates balloted for had been unanimously elected, the names of these gentlemen being as follows:—

AS MEMBERS:—

Mr JAMES L. CRICHTON, Engineer, 3 East Park Terrace, Maryhill.
Mr JAMES D. PEAT, Mechanical Engineer, Finnieston Quay.
Mr MATTHEW TAYLOR BROWN, Engineer, 194 St. Vincent Street.
Mr ANDREW T. REID, Mechanical Engineer, Hydepark Locomotive Works, Glasgow.
Mr JOHN REID, Mechanical Engineer, Hydepark Locomotive Works, Glasgow.

AS GRADUATES:—

Mr J. POLLOCK BROWN, Apprentice Engineer, 2 Park Grove Terr.
Mr TOM JEFFERSON FRYER, Student Engineer, 24 Claremont Street.
Mr CHARLES F. A. FYFE, Apprentice Mechanical Engineer, 48 Rosebank Terrace.
Mr WILLIAM A. GOVAN, Apprentice Engineer, Thornton Hall.
Mr JAMES A. SMITH, Marine Engine Draughtsman, Union Bank House, Virginia Place.
Mr JOHN MACINTOSH, Apprentice Engineer, 7 Park Quadrant.

THE FOURTH GENERAL MEETING of the THIRTY-EIGHTH SESSION of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 22nd January, 1895, at 8 P.M.

Mr JOHN INGLIS, President, in the Chair.

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The Minute of General Meeting of 18th December, 1894, was read and approved, and signed by the President.

The discussion of the paper on "A New Mining Motor," by Mr HENRY A. MAVOR, was continued and terminated, and a vote of thanks awarded Mr Mavor.

The discussion of Mr GEORGE C. THOMSON'S paper on "Results of Evaporative Tests on Land Boilers," was deferred until next General Meeting.

A paper on "Water Tube Boilers," by Professor WATKINSON, was read; the discussion being deferred to next General Meeting.

The paper on "Electrical Transmission of Power in Shipyards and on board Merchant Steamers," by Mr W. CARLILE WALLACE, was held as read.

The President introduced Sir W. H. WHITE, K.C.B. (elected an Honorary Member last session), who made some interesting remarks on the work of the Institution.

The President intimated that the Candidates balloted for had been unanimously elected, the names of these gentlemen being as follows:—

AS MEMBERS:—

Mr THOS. FLEMING, Mechanical Engineer, Atlas Works, Springburn.

Mr GEORGE L. FLETT, Mechanical Engineer, 86 Sussex Street, Paisley Road West.

Mr CHARLES SCOTT GALLOWAY, Mechanical Engineer, 676 Dumbarton Road, Partick.

Mr THOMAS HILL, Mechanical Engineer, 3 Whitevale, Dennistoun.

Mr ROBERT COLVILLE MATHEWSON, Mechanical Engineer, 18 Wellington Street, Greenock.

Mr DAVID MARSHALL, Mechanical Engineer, Glasgow Tube Works, Glasgow.

Mr ALEXANDER W. PATTIE, Mechanical Engineer, University Gardens Terrace, Hillhead.

Mr J. MILLEN ADAM, Ibrox Iron Works, Glasgow.

Mr WILLIAM RUSSELL FERGUSON, Messrs Barclay, Curle & Co., Whiteinch.

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Mr W. B. GOWAN, Naval Construction and Armaments Company, Barrow-in-Furness.

AS ASSOCIATES:—

Mr A. L. CLAUSSEN, Agent and Merchant in Shipbuilding and Engineering Requirements, 118 Broomielaw.

Mr JOHN HUNTER, Secretary, Sir William Arrol & Company, 101 Armadale Street, Glasgow.

AS GRADUATES:—

Mr JAMES A. DIACK, Mechanical Engineering Draughtsman, Bon-Accord, Dumbreck, Glasgow.

Mr PETER FERGUSON, Jr., Assistant Mechanical Engineer, Fergus Villa, Paisley.

Mr LOUIS FERGUSON, Shipbuilding Draughtsman, Fergus Villa, Paisley.

Mr GERARD HUDSON, Apprentice Engineer, 140 West Princes Street, Glasgow.

Mr GEORGE M'INTOSH, App. Engineer, Dunglass Cottage, Bowling.

Mr JOHN M'INTOSH, Marine Draughtsman, Oak Bank, Bowling.

THE FIFTH GENERAL MEETING of the THIRTY-EIGHTH SESSION of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 26th February, 1895, at 8 P.M.

Mr HENRY A. MAVOR, Vice-President, in the Chair.

The Minute of General Meeting of 22nd January, 1895, was read and approved, and signed by the Chairman.

The discussion of Mr GEORGE C. THOMSON'S paper on "Results of Evaporative Tests on Land Boilers" was proceeded with and terminated.

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The discussion of paper on "Water Tube Boilers," by Professor WATKINSON, was proceeded with and terminated.

Votes of thanks were awarded the authors.

The discussion of the paper on "Electrical Transmission of Power in Shipyards and on board Merchant Steamers," by Mr W. CARLILE WALLACE, was deferred to next General Meeting.

The paper on "The Strength of Ships' Beams," by Mr W. DAVID ARCHER, was held as read; and Professor JAMIESON'S remarks on "A New Development in Steam Engine Economy" were postponed till next General Meeting.

The Chairman intimated that the Candidates balloted for had been unanimously elected, the names of these gentlemen being as follows:—

AS MEMBERS:—

Mr STUART BELL, Engineer, 41 Clyde Place.

Mr WALTER DIXON, Electrical and Mechanical Engineer, 164 St. Vincent Street.

Mr R. H. B. THOMSON, Shipbuilder, Govan Shipbuilding Yard, Govan.

Mr EBEN. HALL BROWN, Helen Street Engine Works, Govan.

AS GRADUATES:—

Mr IRVINE KEMPT, Jr., Mechanical Engineering Student, Foresthill, Kelvinside.

Mr THOMAS RUSSELL STOVE, Assistant Mechanical Draughtsman, 5 Craigmore Terrace, Partick.

THE SIXTH GENERAL MEETING of the THIRTY-EIGHTH SESSION of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 26th March, 1895, at 8 P.M.

Mr GEORGE RUSSELL, Vice-President, in the Chair.

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The Minute of General Meeting of 26th February, 1895, was read and approved, and signed by the Chairman.

The Chairman referred, in fitting terms, to the death of Mr LINDSAY BURNET, who was a Member of Council of the Institution.

On the motion of Mr H. A. MAVOR, seconded by Mr ROBERT DUNDAS, Messrs Peter Stewart and W. A. Charlton were appointed Auditors of the Annual Accounts.

The following papers were read :—

On "The Extension of Loch Katrine Water Works," by Mr JAMES M. GALE, M.Inst.C.E.

On "The Drawing Office," by Mr ARCHIBALD DENNY.

The discussion of paper on "Electrical Transmission of Power in Shipyards and on board Merchant Steamers," by Mr W. CARLILE WALLACE, was proceeded with and continued to next General Meeting.

The discussion of paper on "The Strength of Ships' Beams," by Mr W. DAVID ARCHER, and the reading of paper on "A New Development in Steam Engine Economy, with Descriptions of Tests of Field's Engine," by Professor JAMIESON, M.Inst.C.E., F.R.S.E., were deferred to next General Meeting.

The Chairman intimated that the Candidates balloted for had been unanimously elected, the names of these gentlemen being as follows:—

AS MEMBERS :—

Mr O. R. ANBULL, Engineer, 8 St. Alban's Terrace, Partick.

Mr W. S. CAMPBELL, Shipyard Manager, 5 Buckingham Terrace, Partick.

Mr JOHN CRAIG, Engineer, Rosevale, Port-Glasgow.

Mr WALTER DRUMMOND, Mechanical Engineer, The Glasgow Railway Engineering Works, Govan.

Mr JOHN GORDON, Mechanical Engineer, 152 Craigpark Street.

Mr FRED. N. HENDERSON, Shipbuilder, Meadowside, Partick.

Mr JAMES H. HUTCHISON, Shipbuilder, Port-Glasgow.

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Mr J. Foster King, Naval Architect, The British Corporation, 69 St. Vincent Street.

Mr Wm. Andrew Young, Engineer, Millburn House, Renfrew.

AS ASSOCIATES:—

Mr Walter Lyon Fisher, Confidential Clerk and Cashier, Glenburn Ironworks, Greenock.

Mr Lawrence MacBrayne, of Glasgow and West Highland Steamers, 11 Park Circus Place.

AS GRADUATES:—

Mr Gilbert Goodwin, Jr., Marine Engineering Draughtsman, 20 Carmichael Street, Govan.

Mr John Orr, Engineering Student, c/o Mrs Reid, Raglan Place, Partick.

The Thirty-eighth Annual General Meeting of the Institution was held in the Hall of the Institution, 207 Bath Street, on Tuesday, the 30th April, 1895, at 8 P.M.

Mr John Inglis, President, in the Chair.

The Minute of General Meeting of 26th March, 1895, was read and approved, and signed by the President.

The Treasurer's Annual Financial Statement, duly audited, was submitted and adopted.

A vote of thanks was awarded the Auditors, Messrs Peter Stewart and W. A. Charlton.

The following awards were made for Papers read Session 1893-94:

Premiums of Books were awarded to Mr William Arnot for his paper on "The Glasgow Corporation Electric Light Supply;" and

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to Mr ALEXANDER MORTON for his paper on "Rotatory and Reaction Engines."

The Election of Office-Bearers then took place :—

On the motion of the President, seconded by Mr C. P. Hogg, Sir WILLIAM ARROL was unanimously elected President.

On the motion of Mr James Mollison, seconded by Mr J. M. Gale, Prof. ANDREW JAMIESON was unanimously elected a Vice-President.

And, by a majority of votes, the following gentlemen were elected Councillors :—Messrs SINCLAIR COUPER, JAMES DENNY, GEORGE RUSSELL, JOHN DUNCAN, ROBERT CAIRD, and WILLIAM FOULIS.

Mr J. M. GALE was unanimously re-elected Honorary Treasurer.

Prof. JAMIESON'S paper on "A New Departure in Steam Engine Economy, with a Description and Tests of Field's Combined Steam and Hot Air Engine," was read.

The discussions of the following papers took place, viz. :—

On "Electrical Transmission of Power in Shipyards and on board Merchant Steamers," by Mr W. CARLILE WALLACE.

On "The Strength of Ships' Beams," by Mr W. DAVID ARCHER.

On "The Extension of Loch Katrine Water Works," by Mr JAMES M. GALE, M.Inst.C.E., and

On "The Drawing Office," by Mr ARCHIBALD DENNY.

Votes of thanks were awarded the authors.

The discussions on Professor Jamieson's and on Mr Gale's papers were continued to opening meeting of next session.

The President announced that the Candidates balloted for had been unanimously elected, the names of these gentlemen being as follows :—

AS A LIFE MEMBER :—

Mr FREDERIC JOHN STEPHEN, Shipbuilder, Linthouse, Govan.

AS MEMBERS :—

Mr ROBERT ALLAN, Engineer, Demerara Foundry, George Town, Demerara.

Mr HENRY WILLIAM BROCK, Mechanical Engineer, Engine Works, Dumbarton.

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Mr ALEX. M'A. KENNEDY, General Shipyard Manager, Rosslea, Dumbarton.

Mr EDMUND SHARER, Shipbuilder, 8 Belhaven Crescent, Glasgow.

Mr WILLIAM WILSON, Mechanical Engineer, Lilybank Boiler Works, Glasgow.

Mr LESLIE DENNY, Shipbuilder, Leven Shipyard, Dumbarton.

On the motion of Mr J. M. Gale, a hearty vote of thanks was awarded the President on his retiral from the Presidential chair.

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TREASURER'S STATEMENT—1894-95.

GENERAL FUND.

Dr.					Cr.		
To Balance in Union Bank at close of Session 1893-94,			£693	0 7	*By* Amount paid Treasurer of House Committee as Institution's proportion of Expenditure, for Session 1894-95,...	£125	0 0
Subscriptions received:					Printing, ...	156	10 0
Session 1894-95, ...	£742	5 0			Lithography, ...	78	11 3
Arrears of Previous Sessions,	67	15 0			Premiums for Papers, ...	15	0 6
	£810	0 0			Graduate Section Medal, ...	1	7 6
Deduct Entry Money transferred to Building Fund, ..	10	15 0			Salary to Secretary, ...	150	0 0
			799	5 0			
Sales of Transactions, ...			5	12 3	Commission Collection of Arrears of Subscriptions, viz. :—		
Bank Interest, ...			2	16 8	For Session 1894-95, ... £453 15 0		
Interest from Clyde Trust, ...			4	14 3	For Previous Sessions, ... 67 15 0		
					£521 10 0 at 5 %	26	1 6
					Postages, ...	39	15 10
					Delivery of Annual Volumes, ...	6	13 10
					Stationery, Insurance, &c., ...	14	12 1
					James Watt Anniversary Dinner, ...	18	6 2
					Binding Periodicals in Library, ...	8	7 0
					Reporting, ...	13	4 6
					Cash to New Buildings Account to meet Interest on Loan, from Medal Funds, ...	16	0 0
					Investment in Clyde Trust, ...	300	0 0
					Petty Cash, ...	0	5 7
					Balance in Union Bank, ...	535	13 0
			£1505	8 9		£1505	8 9

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DR. MARINE ENGINEERING MEDAL FUND. CR.

To Balance in Union Bank at close of Session 1893-94, ...	£27	5	8	*By* Medal, ...	£9	18	7
Interest on Capital lent to New Buildings Account,	10	0	0	Balance in Union Bank, ...	30	1	11
,, Mortgage, Glasgow Corporation,	2	15	3				
	£40	0	6		£40	0	6

DR. RAILWAY ENGINEERING MEDAL FUND. CR.

To Balance in Union Bank at close of Session 1893-94, ...	£24	17	9	*By* Balance in Union Bank, ...	£32	2	9
Interest on Capital lent to New Buildings Account,	6	0	0				
,, Mortgage, Glasgow Corporation,	1	5	0				
	£32	2	9		£32	2	9

DR. GRADUATE MEDAL FUND. CR.

To Balance in Union Bank at close of Session 1893-94,	£1	16	4	*By* Balance in Union Bank, ...	£2	12	0
Interest on Mortgage, Glasgow Corporation,	0	15	8				
	£2	12	0		£2	12	0

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DR. BUILDING FUND. CR.

To Balance in Union Bank at close of Session 1893-94,				£61	17	6
Life Member,	...	...	...	20	0	0
Entry Money,	...	...	...	10	15	0
Interest on Mortgage, Glasgow Corporation,				17	0	0
				£109	12	6

By Balance in Union Bank, ...	£109	12	6
	£109	12	6

DR. NEW BUILDINGS ACCOUNT. CR.

To Capital to meet Cost of New Buildings, viz.:—						
From General Fund, ...	£542	15	7			
,, Marine Engineering Medal Fund, ...	351	11	2			
,, Railway Engineering Medal Fund, ...	213	13	3			
,, Building Fund, ...	939	8	1			
				£2047	8	1
Cash received from General Fund to meet Interest on Loans, ...				16	0	0
				£2063	8	1

By Paid on New Buildings, ...				£2047	8 1
Interest on Loans, viz.:—					
To Marine Engineering Medal Fund,	£10	0	0		
,, Railway Engineering Medal Fund,	6	0	0		
				16	0 0
				£2063	8 1

GLASGOW, *11th April, 1895.*—We have examined the foregoing Annual Financial Statement of Treasurer, the Accounts of the Marine and Railway Engineering Medal Funds, the Graduate Medal Fund, the Building Fund, and the New Buildings Account, and find the same duly vouched and correct, the Amounts in Bank being as stated.

(Signed) PETER STEWART, W. A. CHARLTON, } AUDITORS.

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DR. SUBSCRIPTION ACCOUNT. CR.

To Subscriptions due as per Roll, viz.:—								*By* Subscriptions received, as per Cash Book, viz.:—		
Arrears due at close of last Session, ...			£141	15	0			Arrears of Subscriptions previous to Session 1894-95, ...	£67	15
Deduct Irrecoverable and Deceased,			29	0	0					
			£112	15	0			SESSION 1894-95:—		
Add elected at Annual General Meeting of 24th April, 1894, ...			7	0	0			375 Members at £1 10 0 —	£562	10 0
SESSION 1894-95:—						£119	15 0	5 New Members ,, 2 10 0 —	12	10 0
439 Members at £1 10 0 —	£658	10	0					9 ,, ,, 2 0 0 —	18	0 0
5 New Members ,, 2 10 0 —	12	10	0					17 ,, ,, 1 10 0 —	25	10 0
9 ,, ,, 2 0 0 —	18	0	0					25 Associates ,, 1 0 0 —	25	0 0
20 ,, ,, 1 10 0 —	30	0	0					2 New Associates ,, 1 10 0 —	3	0 0
28 Associates ,, 1 0 0 —	28	0	0					1 ,, ,, 1 5 0 —	1	5 0
2 New Associates ,, 1 10 0 —	3	0	0					189 Graduates ,, 0 10 0 —	94	10 0
2 ,, ,, 1 5 0 —	2	10	0						742	5 0
237 Graduates ,, 0 10 0 —	118	10	0					Arrears due for Session 1894-95, ...	£128	15 0
						871	0 0	Arrears due for previous Sessions,	52	0 0
									180	15 0
						£990	15 0		£990	15 0

DR. BANK ACCOUNT. CR.

To Balances at close of Session 1893-94:—								*By* Amounts Drawn, Session 1894-95, ...	£929	13 10
General Fund, ...	£693	0	7					Balances in Union Bank, ...	710	2 2
Marine Engineering Medal Fund, ...	27	5	3							
Railway Engineering Medal Fund, ...	24	17	9							
Graduate Medal Fund, ...	1	16	4							
Building Fund, ...	61	17	6							
Amounts lodged, Session 1894-95, ...	828	1	11							
Interest, Session 1894-95, ...	2	16	8							
						£1639	16 0		£1639	16 0

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CAPITAL ACCOUNT.

GENERAL FUND.

Loan to New Buildings Account, ...	£542 15 7		
Mortgage, Glasgow Corporation, ...	35 0 0		
Do. Clyde Trust, ...	300 0 0		
Cash in Union Bank, ...	535 13 0		
		£1,413	8 7

MARINE ENGINEERING MEDAL FUND.

Loan to New Buildings Account, ...	£351 11 2		
Mortgage, Glasgow Corporation, ...	90 0 0		
Cash in Union Bank, ...	30 1 11		
		471	13 1

RAILWAY ENGINEERING MEDAL FUND.

Loan to New Buildings Account, ...	£213 13 3		
Mortgage, Glasgow Corporation, ...	40 0 0		
Cash in Union Bank, ...	32 2 9		
		285	16 0

GRADUATE MEDAL FUND.

Mortgage, Glasgow Corporation, ...	£25 0 0		
Cash in Union Bank, ...	2 12 0		
		27	12 0

BUILDING FUND.

Amount to New Buildings Account, ...	£939 8 1		
Mortgage, Glasgow Corporation, ...	560 0 0		
Cash in Union Bank, ...	109 12 6		
		1,609	0 7

ARREARS OF SUBSCRIPTIONS.

Arrears due for Session 1894-95, ...	£128 15 0		
Do. previous Sessions, ...	52 0 0		
		180	15 0
		£3,988	5 8

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DR. HOUSE EXPENDITURE ACCOUNT. (ABSTRACT 1894-95.) CR.

To Rents for Letting Rooms, ...					£54	0	0
Amounts Received by Treasurer to meet Expenses, viz.:—							
From Institution of Engineers and Shipbuilders, ...	£125	0	0				
From Philosophical Society, ...	155	4	5				
				280	4	5
Property Tax returned, ...				1	2	0
Balance due Treasurer, ...				31	3	5
				£366	9	10

By Balance due Treasurer					£9	5	11
Interest on Bond, ...					116	5	0
Salary to Curator, ...					100	0	0
Salary to Attendant at Library, Cleaning, &c., ...					52	1	3
Taxes, ...					29	4	9
Feu-duty, etc., ...					0	18	9½
Gas Rates, ...					16	8	0½
Water Rates, ...					5	14	8
Coals, ...					16	17	6
Insurance, ...					7	15	0
Repairs and Furnishings, ...					10	17	4
Stationery, etc., ...					1	1	7
					£366	9	10

The Account of the House Committee is kept by Mr John Mann, C.A., Treasurer to the Committee, and is periodically audited by the Auditors appointed by the Institution and the Philosophical Society.

W. J. MILLAR, *Secretary to House Committee.*

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OBITUARY.

Honorary Member.

Professor HERMAN VON HELMHOLTZ was elected an Honorary Member of the Institution in 1884.

As one of the foremost philosophers of the century, his name is of world-wide reputation.

The son of a professor at Potsdam, where he was born in 1821, he studied medicine at Berlin, and became an army surgeon in 1843.

In 1848 he was appointed Professor of Anatomy at Berlin, and afterwards held in succession the following chairs:—

Physiology, at Königsberg, 1849,
Anatomy and Physiology, at Bonn, 1855,
Physiology, at Heidelberg, 1858,
and Physics, at Berlin, 1871.

Professor Helmholtz published many works upon physical subjects, notably:—On "The Preservation of Forces," 1847; "Physiological Optics," 1856; "Theory of the Impressions of Sound," 1862; "Popular Lectures on Scientific Subjects," 1873.

By command of the German Emperor, Professor Helmholtz was raised to "the Status of Nobility" in 1883.

He died at Charlottenburg, on 8th September, 1894.

Members.

Mr LINDSAY BURNET joined the Institution as a Graduate in 1876. He became a Member of the Institution in 1889, and at the time of his death was a Member of the Council.

Mr Burnet frequently took part in the discussions arising out of the various papers read.

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Mr Burnet served his apprenticeship to engineering in the works of Messrs Barclay, Curle & Co., and those of Messrs T. Wingate & Co., Whiteinch, Glasgow. To improve his knowledge in marine engineering, he went to sea for a short time, and thereafter settled in London, where he studied civil and mechanical engineering. He afterwards returned to Glasgow, and commenced business as an engineer and boiler maker.

Mr Burnet devoted much attention to the proper combustion of fuel and abatement of smoke, and was frequently consulted upon such questions.

He died on 14th March last at the early age of 39, at Dunblane Hydropathic Establishment, where he had gone for the benefit of his health, which had never been very strong.

Mr DAVID CARMICHAEL became a Member of the Institution in 1868. He was a native of Dundee, and after serving his apprenticeship in the Ward Foundry, established by his father and uncle, Messrs Charles and James Carmichael, he went to Bristol, and was draughtsman at the works there when the "Great Britain" was built. Afterwards he was engaged at Woolwich Dockyard. About the year 1850 he returned to Dundee to join his cousin, Mr George Carmichael, in the Ward Foundry, which, under their able management, has had such a prosperous career. Considerable extensions and alterations were made from time to time, so as to meet the demands for larger and more efficient machinery, in all of which Mr Carmichael's great ability and experience were prominently displayed.

Mr Carmichael did not take any active part in political or public questions, but in private, and amongst his workpeople, he was highly esteemed.

He died at Dundee, on 5th May, 1895, aged 78.

Whilst going to press the sad announcement has been made of the death of Dr PETER DENNY, of Dumbarton.

Dr Denny joined the Institution in 1865, having formerly been a

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Member of the Scottish Shipbuilders' Association, founded in 1860. He held the office of Vice-President of that Society at its inauguration, and was President during Session 1863-64.

Dr Denny was the sixth son of William Denny, of Dumbarton, who did so much by his engineering and shipbuilding skill to improve the early steamers on the Clyde. Along with some of his elder brothers he started iron shipbuilding at Dumbarton in 1844.

Later on, in 1851, Messrs Denny, M'Ausland & Tulloch founded an engineering and boiler making establishment also at Dumbarton.

Besides these enterprises, Dr Denny was partner in other industrial businesses in Dumbarton, and later on in several large well known shipping companies, the success of all being largely determined by Dr Denny's great ability.

In 1871 the British Government appointed him one of the Committee on Designs for Ships of War, and he was one of the Royal Commissioners on Losses at Sea.

Dr Denny had various foreign distinctions conferred upon him, and in 1890 received the degree of LL.D. from the University of Glasgow.

Dr Denny took a deep interest in the welfare of his native town of Dumbarton, in all that related to its social, municipal, religious, and educational life, and had the advancement and training of his workmen much at heart.

In testimony of the esteem in which he was held, many memorials and presentations were made, and recently a movement was put on foot to erect a bronze statue of him in Dumbarton. This statue, by Mr Thorneycroft, sculptor, is now in progress.

Dr Denny died at his residence, Helenslee, Dumbarton, on the 22nd August, in the 74th year of his age.

Mr DAVID HALLEY joined the Institution as a Member in 1876. He was a Member of the Council of the Institution during Sessions 1882-83 and 1883-84.

Mr Halley was a native of Fifeshire. He served his apprenticeship as a marine engineer in the works of Messrs R. Napier & Sons,

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Glasgow, and thereafter he gradually advanced until he held the position of general manager of the engineering department. During that time, his energy and ability found plenty of scope in the various important works turned out by the firm. Amongst others may be noticed the engines of the "Parisian," one of the first steel ocean liners, built and engined by Messrs Napier in 1881.

This vessel was fitted with bilge-keels—an important accessory now getting more generally recognised—to prevent undue rolling. Some years later, Mr Halley left Scotland and became associated with the firm of Messrs Burmeister & Wain, Shipbuilders and Engineers, Copenhagen, and here his abilities were so well recognised that he ultimately became sole managing director. At the time of his death the firm had an important order on hand from the Czar of Russia, in the form of a large and powerful imperial steam yacht.

Mr Halley's great ability was recognised by the King of Denmark, who conferred upon him the order of knighthood.

Mr Halley died at Copenhagen on 4th January, 1895, at the early age of 45.

Mr JOHN HASTIE joined the Institution as a Member in 1864. During Session 1880-81 he contributed a paper on "Screw Nuts, with Differential Threads and Some Applications of Same;" and later on, in Session 1888-89, he contributed a paper on "Special Apparatus for Working the Sails of Ships."

Mr Hastie was a member of the firm of Messrs John Hastie & Co., Greenock, established by Mr Hastie's father in 1850.

Mr Hastie, after serving his apprenticeship with his father, gained further experience by working in Glasgow and Manchester, and finally joined his brother, William, in founding the engineering work in Kilblain Street, Greenock, where, during the last twenty-five years, special appliances for hydraulic and other work have been successfully turned out.

Mr Hastie's inventions are ingenious and are well known. Mr Hastie took considerable interest in philanthropic and church work. He died on Saturday, 22nd September, 1894, aged 50 years.

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Mr JAMES MACRITCHIE was elected a Member of the Institution in 1883. Mr MacRitchie was the son of Mr Alexander MacRitchie, of Greenock, Superintendent Engineer to the Peninsular and Oriental Steamship Company, and was born at Southampton, on the 26th September, 1847. He received his education at Dollar Institution and Edinburgh University, and his early practical training and experience with Messrs Bell & Miller, Civil Engineers, late of this city, taking a prominent part in the construction of dock works at Port-Glasgow, and of bridge work on the rivers Clyde and Kelvin, etc.

After spending some time at Bombay on the water works, and in Japan, where latterly he was Engineer-in-chief in the Government Lighthouse Department; and at Santos, Brazil, where he designed and executed the water and drainage works, and a local tramway, he was appointed Municipal Engineer of Singapore, in 1883. It is with this appointment that his name will be always more particularly associated. His work there may be seen in every direction, in the new roads, bridges, markets, abbatoirs, sanitary arrangements, and water works, amounting to the complete transformation of the town from one of the worst to one of the best equipped cities in the east.

The high esteem with which Mr MacRitchie's work and character were appreciated by the President and the Municipal Commissioners of Singapore, is expressed in the following resolution, unanimously passed at a special meeting of the Commissioners, held 6th May last:—

"That there be recorded in the minutes an expression of the deep regret of the Commissioners at the premature death of Mr James MacRitchie, who has filled the post of Municipal Engineer since August, 1883, with conspicuous success. That the Commissioners recognise the ability, zeal, and patient attention to detail, which characterised all his work, and were gradually winning for him a reputation more than local. That they feel that this municipality is indebted to him for many public works of vast importance, notably for the bountiful supply of water, and for improved roads

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and drains, and that, had his life been spared, works no less important, which he had carefully designed, would probably have been successfully accomplished. That a copy of this resolution be forwarded to Mrs MacRitchie, and that she and her sorrowing friends be assured of the sympathy of the Commissioners, of the ratepayers, and of the public of Singapore, whom her husband long and faithfully served."

Mr MacRitchie's death, which took place 26th April last, was caused by an attack of bronchitis, which developed into laryngitis and congestion of the brain.

Professor SCORGIE joined the Institution as a Member in 1882. He was born at Aberdeen 16th March, 1835, and received an elementary education at one of the parish schools there. On the 15th November, 1850, he was apprenticed for seven years to a firm in that town. In 1854 he attended the lessons in Chemistry at Marishal College. In 1855 he gained the first prize for Chemistry at the Government Examination of the Aberdeen School of Science, which, besides a medal, consisted of a free studentship at Marishal College.

In February, 1858, Mr Scorgie decided to go to London, and from thence he sailed for Bombay in May of that year. He arrived at Bombay in August, and soon after received an appointment in the workshops of the G. I. P. Railway, where he remained for about sixteen months. In January, 1860, he went to Surat, and commenced work in the fitting department of the Bombay, Baroda, and Central India Railway, and remained there till November, 1861. His first work there was the fitting up of the engine "Isabella," which was used at the formal opening of the first portion of this company's line, from Amrolee, on the north bank of the Taptee river, to Unklessor, on the south of the Nerbudda, a distance of 40 miles.

In November, 1861, Mr Scorgie was offered an appointment on the same railway at Bassein; and proceeding thither he put in the coffer dams for the abutments of the large bridge at Bassein. On

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completion of the coffer dams he was appointed superintendent of work on the South Channel Division.

In 1862 Mr Scorgie received an appointment in one of the Mission Colleges at Bombay. After three years in this College, Mr Scorgie was appointed Acting Principal of the Sir Jamsedjee Jeejeebhoy Institution at Bombay, during the absence of the principal for 18 months on sick leave.

In the year 1866 the Government of India commenced educational work in Berar, a province belonging to the Nizam. Mr Scorgie received an appointment there, and six years were spent in the Berar Educational Department.

In 1871 the Maharajah of Jeypore applied to Lord Mayo, requesting that Mr Scorgie might be lent to that State for the purpose of re-organising the well known Jeypore School of Industrial Arts. He remained here for two and a half years. The services which he rendered, and the benefits of his experiments regarding dyeing, and improving the stamping and printing of cloth in Jeypore, were noticed by the Maharajah with much satisfaction, and His Highness was highly gratified with the manner in which Mr Scorgie carried on his duties in every way.

In February, 1875, Mr Scorgie took up his new appointment in the Civil Engineering College, Poona, as Professor of Mechanism and Applied Science, and here were spent the last fifteen years of his Indian career. His services there were much appreciated.

Before leaving College Mr Scorgie published "A Short Treatise on Building Materials."

He was elected a Fellow of the Bombay University in 1868, and a Fellow of the Chemical Society in 1863; and was one of the Original Members of the Society of Chemical Industry.

On his retirement from Her Majesty's East Indian Educational Service, in 1890, he returned to Scotland.

He died at Aberdeen, on 15th July, 1895.

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REPORT OF THE LIBRARY COMMITTEE.

THE additions to the Library during the present session include 72 volumes by purchase, 17 volumes, 13 parts, and 8 pamphlets by donation, while 65 volumes and 34 parts were received in exchange for the Transactions of the Institution. Of the periodical publications received in exchange, 18 are weekly, 15 monthly, and 2 quarterly.

60 volumes were bound during the session.

The Library now consists of 2117 volumes.

On behalf of the Institution, the Committee begs to tender its best thanks for the presentations made.

DONATIONS TO LIBRARY.

Errors of Measurements of Power by the Steam Engine Indicator, by Professor D. S. Jacobus. From the Author.

How to obtain Patents for Inventions and maintain them, by Mr Wallace Fairweather, C.E. From the Author.

Transactions of the American Society of Naval Architects and Marine Engineers, Vols I. and II.; 4to. New York, 1893-94. From the Society.

Development of the Theory of the Flow of Water in Channels, by J. M. Gale, M.Inst.C.E.; 8vo pamphlet, 1893. From the Author.

On the Whirling and Vibration of Shafts, by Stanley Dunkerley; 4to pamphlet, 1893. From the Author.

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Duty Tests of Pumping Engines, and Reynold's Corliss Engines, by The Edward P. Allis Company, Milwaukee. From the Company.

Journal of the West of Scotland Iron and Steel Institute, Vol. I., 1892-94, and continued. From the Institute.

North of England Institute of Mining Engineers; Report of the Proceedings of the Flameless Explosives Committee, Part I.—Air and Combustible Gases, by A. C. Kayll, 1894. From the Institute.

Kitchen Boiler Explosions; why they occur, and how to prevent their occurrence, by R. D. Munro. From the Author.

Spons' Engineers' and Contractors' Diary and Year Book, 1895. From Messrs E. & F. N. Spon.

Transactions of the American Institute of Electrical Engineers, Vol. XII., Parts 1-8; 1895, and continued. From the Institute.

Spons' Engineers' and Contractors' Illustrated Book of Prices, 1895-96. From Messrs E. & F. N. Spon.

Cornell University Register, 1894-95. From the University.

Massachusetts Institute of Technology, Annual Report and Catalogue, for 1894-95. From the Institute.

Tehuantepec Isthmus Railway, by Romero and Corthell; 8vo pamphlet. From the Authors.

Report on the Walker-Wilkins Patent Non-Polarizing Voltaic Battery; 8vo pamphlet. From Professor Jamieson.

Queensland Water Supply, Report for 1894. From Mr J. B. Henderson, M.Inst.C.E.

Report of the Glasgow and West of Scotland Smoke Abatement Association, by G. C. Thomson; 8vo pamphlet, 1893. From the Author.

Report of the British Association for the Advancement of Science, 1894. From the Association.

British Corporation for the Survey and Registration of Shipping, Rules and Tables of Scantlings, and Register of Vessels, 1895. 4to; Glasgow. From the Corporation.

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Massachusetts Institute of Technology; Technology Quarterly, and Proceedings of the Society of Arts, Vol. V., Part 4, 1892. From the Institute.

Report of the Mitchell Library, 1892-94. From the Librarian.

Smoke Abatement with reference to Steam Boiler Furnaces, by G. C. Thomson; 8vo pamphlet, 1895. From the Author.

Report of Baillie's Institution Free Library, Glasgow, 1894-95. From the Librarian.

Papers read before the Engineering Society of the School of Practical Science, Toronto, No. 8, 1894-95, and continued; 8vo; Toronto. From the Society.

The Mariner; an International Review of Shipping, Marine Engineering, and Kindred Subjects, Vol. XII., Parts 3 and 4, and continued; 4to, London. From the Publisher.

Engineering and Shipbuilding in the Far East, by W. C. Jack; 8vo pamphlet. From the Author.

Treatise on the Evaporation of Saccharine, Chemical, and other Liquids by the Multiple System, by James Foster; second edition, 8vo; Sunderland, 1895. From the Author.

Catalogue of the Library of the Institution of Civil Engineers, 3 vols. 8vo; London, 1895. From the Institution.

Lloyd's Register, 1894-95, with Rules and Regulations. From the Association.

Glasgow University Calendar, 1895-96. From the University.

Electrical Transmission of Power, by the Electrical Company, London; 8vo. London, 1895. From the Company.

NEW BOOKS ADDED TO THE LIBRARY.

Brassy, T. A., Naval Annual for 1895; 8vo. Portsmouth, 1895.

Buck, G. W., A Practical and Theoretical Essay on Oblique Bridges; 4th edition; Revised by J. H. W. Buck, and with the addition of description to diagrams for facilitating the Construction of Oblique Bridges, by W. H. Barlow; 8vo. London, 1895.

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Burr, W. H., Elasticity and Resistance of the Materials of Engineering; 4th edition; 8vo. New York, 1894.

Burr, W. H., Stresses in Bridge and Roof Trusses; 9th edition; 8vo. New York, 1894.

Burton, W. K., Water Supply of Towns, and the Construction of Waterworks, to which is appended a paper on the Effects of Earthquakes on Waterworks, by John Milne; 8vo. London, 1894.

Church, Irving P., Mechanics of Engineering; 8vo. New York, 1894.

Colson, C., Notes on Docks and Dock Construction; 8vo. London, 1894.

Crosby, O. T., and Louis Bell, Electric Railway, in theory and practice; 2nd edition; 8vo. New York, 1893.

Diesel, Rudolf, Theory and Construction of a Rational Heat Motor; Translated by Bryan Donkin; 8vo. London, 1894.

Donkin, Bryan, Text-Book on Gas, Oil, and Air Engines; 8vo. London, 1894.

Draper, C. H., Heat, and the Principles of Thermodynamics; 8vo. London, 1893.

Du Bois, A. Jay, Elementary Principles of Mechanics. Vol. I., Kinematics; 8vo. New York, 1894.

Electrical Trades' Directory and Handbook for 1895; 8vo. London, 1895.

Ewing, J. A., Steam Engine and other Heat Engines; 8vo. London, 1894.

Ewing, J. A., Magnetic Induction in Iron and other Metals; 2nd issue. New York and London, 1893.

Fidler, T. C., A Practical Treatise on Bridge Construction; 2nd edition; 8vo. London, 1893.

Flather, J. J., Dynamometers and the Measurement of Power; 8vo. New York, 1893.

Glazebrook, R. T., Laws and Properties of Matter; 8vo. London, 1893.

Gore, G., Art of Electrolytic Separation of Metals, etc.; 2nd edition; 8vo. London, 1894.

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Greene, C. E., Trusses and Arches, analysed and discussed by graphical methods, 3 vols.—

Vol. I., Roof-Trusses; revised edition.

Vol. II., Bridge-Trusses; 4th edition.

Vol. III., Arches; 2nd edition; 8vo. New York, 1893-94.

Haeder, Herman, Handbook on the Steam Engine, with especial reference to small and medium sized engines; Translated by H. H. P. Powles; 8vo. London, 1893.

Jamieson, A., Text-Book on Steam and Steam Engines; 10th edition; 8vo. London, 1895.

Johnson, J. B., Bryan, and Turneaure, Theory and Practice of Modern Framed Structures; 2nd edition; 8vo. New York, 1894.

Kapp, Gisbert, Dynamos: Alternators and Transformers; 8vo. London, 1893.

Kapp, Gisbert, Electric Transmission of Energy; 4th edition; 8vo. London, 1894.

Kapp, Gisbert, Alternating Currents of Electricity, their Generation, Measurement, Distribution, and Application; 8vo. New York, 1893.

Kempe, H. R., Engineers' Year-Book of Formulæ, Rules, Tables, Data, and Memoranda in Civil, Mechanical, Electrical, Marine, and Mine Engineering; 8vo. London, 1895.

Laslett, Thomas, Timber and Timber Trees, Native and Foreign; 2nd edition; Revised by H. M. Ward; 8vo. London, 1894.

Lineham, W. J., Text-Book of Mechanical Engineering; 8vo. London, 1894.

Lodge, O., Modern Views of Electricity; 8vo. London, 1892.

Lodge, O., Lightning Conductors and Lightning Guards; 8vo. London, 1892.

Merriman, M., and H. S. Jacoby, Text-Book on Roofs and Bridges. Part III., Bridge Design; 8vo. New York, 1894.

Merriman, M., Treatise on Hydraulics; 5th edition; 8vo. New York, 1895.

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Merriman, M., Text-Book on the Mechanics of Materials, and of Beams, Columns, and Shafts; 5th ed.; 8vo. New York, 1894.

Minchin, G. M., Hydrostatics and Elementary Hydrokinetics; 8vo. Oxford, 1892.

Munro, John, and A. Jamieson, Pocket-Book of Electrical Rules and Tables for the use of Electricians and Engineers; 48mo. London, 1894.

Newman, John, Notes on Cylinder Bridge Piers, and the Well System of Foundations; 8vo. London, 1893.

Peabody, C. H., Tables of the Properties of Saturated Steam and other Vapours; 6th edition; 8vo. New York, 1895.

Peabody, C. H., Thermodynamics of the Steam Engine and other Heat Engines; 3rd edition; 8vo. New York, 1895.

Phillips, Philip, Forth Bridge in its Various Stages of Construction, and compared with the most Notable Bridges of the World; 2nd edition; folio. Edinburgh, no date.

Pickworth, C. N., Slide Rule: A Practical Manual; 8vo. Manchester, 1894.

Preston, Thomas, Theory of Heat; 8vo. London, 1894.

Price, W. A., Treatise on the Measurement of Electrical Resistance; 8vo. Oxford, 1894.

Ram, G. S., Incandescent Lamp and its Manufacture; 8vo. London, 1893.

Rankine, W. J. M., Manual of Civil Engineering; 19th edition; Revised by W. J. Millar; 8vo. London, 1894.

Rankine, W. J. M., Manual of Applied Mechanics; 14th edition; Revised by W. J. Millar; 8vo. London, 1895.

Searles, W. H., Field Engineering; 16th edition; 8vo. New York, 1895.

Simms, F. W., and D. K. Clark, Practical Tunnelling; 3rd edition; 8vo. London, 1877.

Slingo, W., and A. Brooker, Electrical Engineering; new edition; 8vo. London, 1895.

Stock, C. H., Treatise on Shoring and Underpinning; 2nd edition; 8vo. London, 1893.

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Stromeyer, C. E., Marine Boiler Management and Construction; 8vo. London, 1893.

Sutcliffe, G. W., Steam Power and Mill Work; 8vo. London, 1895.

Thompson, S. P., Elementary Lessons in Electricity and Magnetism; new edition; 8vo. London, 1895.

Turner, J. H. T., and A. W. Brightmore, Principles of Waterworks Engineering; 8vo. London, 1893.

Unwin, W. C., Development and Transmission of Power from Central Stations, being the Howard Lectures for 1893; 8vo. London, 1894.

Waddell, J. A. L., Designing of Ordinary Iron Highway Bridges; 5th edition; 8vo. New York, 1894.

Weisbach, Julius, Manual of the Mechanics of Engineering and of the Construction of Machines, 3 vols.; 8vo. New York, 1890-94.

Wilson, R., Treatise on Steam Boilers, their Strength, Construction, and Economical Working; 5th edition; 8vo. London, 1879.

Wilson, R., Boiler and Factory Chimneys, their Draught, Power, and Stability, with a chapter on Lightning Conductors; 3rd edition; 8vo. London, 1892.

Yeo, John, Steam and the Marine Steam Engine; 8vo. London, 1894.

Cooke, C. J. B., British Locomotives, their History, Construction, and Modern Development; 2nd edition; 8vo. London, 1894.

Emerson, James, Treatise relative to the Testing of Water Wheels and Machinery; 3rd edition; 8vo. Springfield, Mass., 1881.

Greenhill and Unwin, Hydromechanics, being Part 47, 9th edition of Encyclopædia Britannica; 4to. Edinburgh.

Hughes, H. W., Text Book of Coal Mining; 2nd edition; 8vo. London, 1893.

Innes, C. H., Centrifugal Pump, Turbines, and Water Motors; 8vo. Manchester, 1893.

Tesla, Nikola, Experiments with Alternate Currents of High Potential and High Frequency; 8vo. New York, 1892.

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Year Book of the Scientific and Learned Societies of Great Britain and Ireland, 1895.

Mills and Rowan, Chemical Technology, edited by Groves and Thorpe; Vol. I., Fuel and its Applications; 8vo. London, 1889.

THE INSTITUTION EXCHANGES TRANSACTIONS WITH THE FOLLOWING SOCIETIES, &C.:—

Bristol Naturalists' Society, Bristol.
Institution of Civil Engineers, London.
Institution of Civil Engineers of Ireland, Dublin.
Institution of Mechanical Engineers, London.
Institution of Naval Architects, London.
Institute of Marine Engineers, London.
Iron and Steel Institute, London.
Liverpool Engineering Society, Liverpool.
Liverpool Polytechnic Society, Liverpool.
Literary and Philosophical Society of Manchester, Manchester.
Lloyd's Register of British and Foreign Shipping, London.
Manchester Association of Engineers, Manchester.
Midland Institute of Mining, Civil, and Mechanical Engineers, Barnsley.
Mining Institute of Scotland, Hamilton.
North-East Coast Institution of Engineers and Shipbuilders, Newcastle-on-Tyne.
North of England Institute of Mining and Mechanical Engineers, Newcastle-on-Tyne.
Patent Office, London.
Philosophical Society of Glasgow.
Royal Dublin Society, Dublin.
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Shipmasters' Society, London.
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Society of Engineers, London.
South Wales Institute of Engineers, Swansea.

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The Hull and District Institution of Engineers and Naval Architects, Hull.
Institution of Junior Engineers, London.
The Sanitary Institute of Great Britain, London.
West of Scotland Iron and Steel Institute.
Edinburgh Architectural Association.
American Society of Civil Engineers, New York.
American Society of Mechanical Engineers, New York.
Association des Ingénieurs, Gand, Belgium.
Austrian Engineers' and Architects' Society, Vienna.
Bureau of Steam Engineering, Navy Department, Washington.
Canadian Institute, Toronto.
Canadian Society of Civil Engineers, Montreal.
Engineers' and Architects' Society of Naples, Naples.
Geological Survey of Canada, Montreal.
Master Car Builders' Association, Chicago, U.S.A.
Royal Academy of Sciences, Lisbon.
Royal Society of Tasmania, Hobart.
Smithsonian Institution, Washington, U.S.A.
Society of Naval Architects and Marine Engineers, Washington, U.S.A.
Société des Ingénieurs Civils de France, Paris.
Société Industrielle de Mulhouse, Mulhouse.
Société d'Encouragement pour l'Industrie Nationale, Paris.
Société des Anciens Elèves des Ecoles Nationales d'Arts et Métiers, Paris.
Société des Sciences Physiques et Naturelles de Bordeaux, Bordeaux.
The Engineering Association of New South Wales, Sydney.
The Technical Society of the Pacific Coast, San Francisco, U.S.A.
American Institute of Electrical Engineers.
Society of Arts, Massachusetts Inst. of Technology, Boston.

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Dumbarton Free Public Library, Dumbarton.

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Lloyd's Office, London.
Mercantile Marine Service Association, Liverpool.
M'Gill University, Montreal.
Mitchell Library, Glasgow.
Royal Naval College Greenwich.
Stevens Institute of Technology, Hoboken, U.S.A.
Stirling's Library, Glasgow.
The British Corporation for the Survey and Registry of Shipping, Glasgow.
The Advocates' Library, Edinburgh.
The Glasgow and West of Scotland Technical College, Glasgow.
The Yorkshire College, Leeds.
Trinity College, Dublin.
Underwriters' Rooms, Glasgow.
Do. Liverpool.
University College, London.

PUBLICATIONS RECEIVED PERIODICALLY IN EXCHANGE FOR INSTITUTION TRANSACTIONS:—

Cassier's Magazine.
Colliery Guardian.
Engineering.
Industries and Iron.
Iron and Coal Trades' Review.
Iron and Steel Trades' Journal.
Machinery.
Nature.
The Colliery Engineer, U.S.A.
The Contract Journal.
The Engineer.
The Engineering Review.
The Machinery Market.
The Marine Engineer.

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The Mechanical World.
The Practical Engineer.
The Steamship.
Indian Engineering.
Journal de l'Ecole Polytechnic.
L'Industria.
Portfeuille Economique des Machines.
Revue Industrielle.
Stahl und Eisen.
The American Manufacturer and Iron World.
The Indian Engineer.
Transport.

ARCH. BARR, D.Sc.,
Hon. Librarian and Convener.

The Library of the Institution, at the Rooms, 207 Bath Street, is open daily from 9-30 a.m. till 8 p.m.; on Meeting Nights of the Institution and Philosophical Society, till 10 p.m.; and on Saturdays till 2 p.m. Books will be lent out on presentation of Membership Card to the Sub-Librarian.

Members have also the privilege of consulting the Books in the Library of the Philosophical Society.

The use of Library and Reading Room is open to Members, Associates, and Graduates.

The Library is open during Summer from 9-30 a.m. till 5 p.m., and on Saturdays till 2 p.m.

The Portrait Album lies in the Library for the reception of Members' Portraits.

Members are requested when forwarding Portraits to attach Signature to bottom of Carte.

The Library Committee are desirous of calling the attention of Readers to the "Recommendation Book," where entries can be made of titles of books suggested as suitable for addition to the Library.

Copies of Library Catalogue and Supplement, price 6d; or

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separately, 3d each, may be had at the Library, 207 Bath Street, or from the Secretary.

A List of the Papers read and Authors' Names, from the First to the Thirty-third Sessions, will be found in Vol. XXXIII.

As arranged by the Council, a Register Book for Graduates now lies in the Library for the inspection of Members, the object being to assist Graduates of the Institution in finding suitable appointments.

Annual Subscriptions are due at the commencement of each Session, viz. :—

MEMBERS, £1 10s; ASSOCIATES, £1; GRADUATES, 10s.
LIFE MEMBERS, £20; LIFE ASSOCIATES, £15.

Membership Application Forms can be had at the Secretary's Office, 207 Bath Street, or from the Librarian at the Rooms, 207 Bath Street.

The Council, being desirous of rendering the Transactions of the Institution as complete as possible, earnestly request the co-operation of Members in the preparing of Papers for reading and discussion at the General Meetings.

Early notice of such Papers should be sent to the Secretary, so that the dates of reading may be arranged.

Copies of the reprint of Vol. VII., containing paper on "The Loch Katrine Water Works," by Mr J. M. Gale, C.E., may be had from the Secretary; price to Members, 7/6.

Members of this Institution, who may be temporarily resident in Edinburgh, will, on application to the Secretary of the Royal Scottish Society of Arts, at his Office, 117 George Street, be furnished with Billets for attending the Meetings of that Society.

The Meetings of the Royal Scottish Society of Arts are held on the 2nd and 4th Mondays of each month, from November till April, with the exception of the 4th Monday of December.

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LIST

OF

HONORARY MEMBERS, MEMBERS, ASSOCIATES, AND GRADUATES

OF THE

Institution of Engineers and Shipbuilders in Scotland

(INCORPORATED),

AT CLOSE OF SESSION 1894-95.

HONORARY MEMBERS.

1859 Professor CHARLES PIAZZI SMYTH, LL.D., F.R.S.E., Clova, Ripon.

1859 Lord KELVIN, A.M., LL.D., D.C.L., F.R.SS.L. and E., Professor of Natural Philosophy in the University of Glasgow.

1884 Lord ARMSTRONG, C.B., LL.D., D.C.L., F.R.S., Newcastle-on-Tyne.

1891 Lord BRASSEY, K.C.B., D.C.L., 4 Great George Street, Westminster, London, S.W.

1891 Sir HENRY BESSEMER, F.R.S., 165 Denmark Hill, Surrey.

1891 Lord BLYTHSWOOD, Blythswood, Renfrewshire.

1891 Professor A. B. W. KENNEDY, LL.D., F.R.S., 19 Little Queen Street, Westminster, London, S.W.

1891 Sir DIGBY MURRAY, Bart., Board of Trade, London, S.W.

1894 Sir WILLIAM HENRY WHITE, K.C.B., F.R.S., LL.D., Admiralty, London.

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MEMBERS.

DATE OF ELECTION.			
G. 1890, Mar. 25: M. 1895, Jan. 22:	J. Millen	Adam,	Ibrox Iron Works, Glasgow.
1889, Nov. 19:	William	Adam,	98 Dixon Avenue, Crosshill, Glasgow.
1889, Apr. 23:	James	Adamson,	58 Romford Road, Stratford, Essex.
1883, Mar. 20:	Geo. A.	Agnew,	Woodland Villa, Govan, Glasgow.
1889, Oct. 22:	William	Aitchison,	49 Park Rd., W., Glasgow.
1872, Feb. 27:	A. B.	Allan,	Burgh Surveyor, Burgh Chambers, Govan, G'gow.
1890, Jan. 21:	John M.	Allan,	Oak Bank, Shandon.
1895, Apr. 30:	Robert	Allan,	Demerara Foundry, George Town, Demerara.
1869, Jan. 20:	William	Allan, M.P.,	Scotia Engine Works, Sunderland.
1864, Dec. 21:	James B.	Alliott,	The Park, Nottingham.
G. 1880, Feb. 24: M. 1889, Oct. 22:	George	Almond,	Hordern Cottage, Belmont, near Bolton.
G. 1865, Feb. 15: M. 1877, Dec. 18:	Wm. M.	Alston,	50 Sardinia Terrace, Hillhead, Glasgow.
1886, Dec. 21:	Alexander	†Amos,	Sydney, New South Wales.
1886, Dec. 21:	Alexander	†Amos, Jun.,	247 George Street, Sydney, New South Wales.
1895, Mar. 26:	O. R.	Anbull,	8 St. Alban's Ter., Partick, Glasgow.
G. 1874, Feb. 24: M. 1880, Nov. 23:	James	Anderson,	100 Clyde St., Glasgow.
1892, Dec. 20:	James H.	Anderson,	Caledonian Ry., Glasgow.

Names marked thus * were Members of Scottish Shipbuilders' Association at Incorporation with Institution, 1865.

Names marked thus † are Life Members.

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1894, Apr. 24: Prof. Mohamed Anis, Bey, Ministère des Travaux Publics, Cairo.

1860, Nov. 28: Robert Angus, Lugar, Ayrshire.

1887, Dec. 20: W. David Archer, Ravenswood, Dalmuir.

1894, Jan. 23: William Arnot, Engineer, Corporation Electric Lighting, City Chambers, Glasgow.

1875, Dec. 21: Thomas A. Arrol, Germiston Works, Glasgow.

1894, Nov. 20: Thomas Arrol, Jun., 101 Armadale St., Glasgow.

1885, Jan. 27: Sir Wm. †Arrol, LL.D., M.P., 10 Oakley Terrace, Glasgow.

Original: David Auld, 18 Broompark Drive, Dennistoun, Glasgow.

1885, Apr. 28: John Auld, Whitevale Foundry, Glasgow.

1880, Feb. 24: William N. Bain, 40 St. Enoch Square, Glasgow.

1891, Apr 28: Wm. P. C. Bain, Lochrin Iron Works, Coatbridge.

1881, Oct. 25: Allan W. Baird, Eastwood Villa, St. Andrew's Drive, Pollokshields, Glasgow.

1887, Nov. 22: Michael R. Barnett, Ashfield, Pateley Bridge, Yorkshire.

1876, Jan. 25: James Barr, Underwood House, Paisley.

1882, Mar. 21: Prof. Archd. Barr, D.Sc., Royston, Dowanhill.
(Member of Council and Honorary Librarian.)

1881, Mar. 22: George H. Baxter, Clyde Navigation Works, Dalmuir.

1875, Jan. 26: Charles Bell, The Birches, Stirling.

David *Bell, 19 Eton Place, Hillhead, Glasgow.

1880, Mar. 23: Imrie Bell, 204 St. Vincent Street, Glasgow.

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1895, Feb. 26:	Stuart Bell,	41 Clyde Place, Glasgow.
1889, Jan. 22:	W. Reid Bell,	Box No. 2263, Post Office, Johannisberg, S. African Republic.
1890, Jan. 21:	R. J. Beveridge,	Lloyd's Register, 342 Argyle St., Glasgow.
G. 1883, Mar. 20: M. 1884, Nov. 25:	Andrew S. Biggart, (*Member of Council.*)	Baltic House, Baltic Street, Bridgeton, Glasgow.
1884, Mar. 25:	Prof. John Harvard Biles,	Glasgow University, Glasgow.
1890, Mar. 25:	John R. Bird,	10 Morrison St., Glasgow.
1869, Feb. 17:	Geo. M'L. Blair,	127 Trongate, Glasgow.
G. 1884, Jan. 22: M. 1889, Oct. 22:	H. MacLellan Blair,	Clutha Iron Works, Vermont Street, Glasgow.
1867, Mar. 27:	James M. Blair,	Williamcraigs, Linlithgowshire.
1883, Oct. 23:	William L. Bone,	Ant and Bee Works, West Gorton, Manchester.
1891, Jan. 27:	William Bow,	Thistle Works, Paisley.
1874, Jan. 27:	Howard Bowser,	13 Royal Crescent, W., Glasgow.
1890, Mar. 25:	George R. Brace,	William Denny & Sons, Dumbarton.
1880, Mar. 23:	James Brand,	109 Bath Street, Glasgow.
1891, Dec. 22:	Henry Brier,	13 Ailsa Drive, Langside, Glasgow.
G. 1873, Dec. 23: M. 1884, Jan. 22:	James Broadfoot,	55 Finnieston St., Glasgow.
1895, Apr. 30:	Henry W. Brock,	Engine Works, Dumbarton.
1865, Apr. 26:	Walter *Brock,	Engine Works, Dumbarton.
1893, Apr. 25:	Thomas M. Broom,	Oakfield, East Greenock.
1890, Jan. 21:	Alex. F. G. Brown,	Swindrige Muir, Dalry.
1859, Feb. 16:	Andrew *Brown,	London Works, Renfrew.
G. 1876, Jan. 25: M. 1885, Nov. 24:	Andrew M'N. Brown,	23 Herriet Street, Pollokshields, Glasgow.

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G. 1879, Feb. 25: M. 1891, Oct. 27:	A. T.	Brown,	18 Glencairn Drive, Pollokshields.
G. 1883, Dec. 18: M. 1895, Feb. 26:	Eben. H.	Brown,	Helen St. Engine Works, Govan, Glasgow.
1886, Mar. 23:	George	Brown,	Kirklee, Dumbarton.
G. 1886, Oct. 26: M. 1892, Jan. 26:	James	Brown,	Engine Department, Astilleros del Nervion, Bilbao, Spain.
G. 1881, Jan. 25: M. 1894, Dec. 18:	Matt. T.	Brown, B.Sc.,	194 St. Vincent Street, Glasgow.
1885, Apr. 28:	Walter	Brown,	Castlehill, Renfrew.
G. 1874, Jan. 27: M. 1884, Jan. 22:	William	Brown,	Meadowflat, Renfrew.
1880, Dec. 21:	William	Brown,	Albion Works, Woodville Street, Govan, Glasgow.
1889, Dec. 17:	William	Brown,	2 Beechwood Ter., Langside, Glasgow,
1890, Mar. 25:	William	Brown,	Old Hall, Kilmalcolm.
G. 1872, Oct. 24: M. 1885, Nov. 22:	Hartvig	Burmeister,	Rahr & Raundrup, 1 Princess Street, Manchester.
1880, Dec. 21:	James W.	Burns,	74 Broomielaw, Glasgow.
1881, Mar. 22:	Thomas	Burt,	60 St. Vincent Crescent, Glasgow.
1878, Oct. 29:	Edward B.	Caird,	777 Commercial Rd., Limehouse, London.
1894, Feb. 20:	Robert	Caird,	Caird & Co., Greenock.
1878, Dec. 17:	James	Caldwell,	130 Elliot Street, Glasgow.
1890, Feb. 25:	Donald	Cameron,	Municipal Offices, Exeter.
1885, Mar. 24:	John B.	Cameron,	111 Union Street, Glasgow.
1875, Dec. 21:	J. C.	Cameron,	24 Pollok Street, Glasgow.
1889, Apr. 23:	John	Cameron,	London Works, Renfrew.
1890, Mar. 25:	William	Cameron,	Fereneze Ter., Barrhead.
1890, Jan. 21:	John	Campbell,	8 Broomhill Drive, Partick.
1895, Mar. 26:	W. S.	Campbell,	5 Buckingham Ter., Partick, Glasgow.

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1889, Oct. 22 : Evelyn G.	Carey,	4 Sunnyside Avenue, Uddingston.
1881, Nov. 22: John H.	Carruthers,	Ashton, Queen Mary Av., Crosshill, Glasgow.
1892, Feb. 23: James	Chalk,	68 Bath Street, Glasgow.
1894, Jan. 23: W. A.	Charlton,	96 Hope Street, Glasgow.
1893, Apr. 25: R. Barclay	Christie,	123 Hope Street, Glasgow.
1883, Jan. 23: John	Clark,	British India Steam Navigation Co., 9 Throgmorton Av., London, E.C.
1893, Apr. 25: William	Clark,	208 St. Vincent Street, Glasgow.
1892, Nov. 22: Alexander	Cleghorn,	Datcha, Scotstounhill, Glasgow.
1891, Oct. 27: Charles	Clarkson,	Portland Harbour Torpedo Works, Weymouth.
1884, Feb. 26: James T.	Cochran,	Cochran & Co., Shipbuilders, Birkenhead.
1890, Mar. 25: John	Cochrane,	Grahamstone Foundry, Barrhead.
1881, Oct. 25: George	Cockburn,	24 Sussex Street, Glasgow.
G. 1876, Dec. 19: / M. 1884, Mar. 25: Charles	Connell,	Whiteinch, Glasgow.
G. 1877, Dec. 18: / M. 1885, Nov. 24: James	Conner,	Assistant Locomotive Engineer, Highland Railway, Inverness.
1893, Dec. 19: James	Cooper,	Aberdeen Steam Navigation Company, Aberdeen.
1864, Feb. 17: James	Copeland,	16 Pulteney St., Glasgow.
1864, Jan. 20: William R.	Copland,	146 West Regent Street, Glasgow.
1868, Mar. 11: S. G. G.	Copestake,	Glasgow Locomotive Works, Little Govan, Glasgow.
1892, Oct. 25: Elmer L.	Corthell,	71 Broadway, New York.
G. 1880, Dec. 21 / M. 1891, Oct. 27 Sinclair	Couper,	Moore Park Boiler Works, Govan, Glasgow.

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1866, Nov. 28:	M'Taggart	Cowan,	109 Bath Street, Glasgow.
1861, Dec. 11:	William	Cowan,	46 Skene Ter., Aberdeen.
1895, Mar. 26:	John	Craig,	Rosevale, Port-Glasgow.
1883, Dec. 18:	Samuel	Crawford,	John Scott & Co., Engineers & Shipbuilders, Kinghorn.
1894, Dec. 18:	James L.	Crichton,	3 East Park Terrace, Maryhill, Glasgow.
1881, Mar. 22:	William	Crockatt,	26 Nithsdale Drive, Pollokshields, Glasgow.
1872, Nov. 26:	David	Cunningham,	F.R.S.E., Harbour Chambers, Dundee.
1884, Dec. 23:	Peter N.	Cunningham,	Easter House, Kennyhill, Cumbernauld Road, Glasgow.
1869, Jan. 20:	James	Currie,	16 Bernard Street, Leith.
1893, Apr. 25:	Thomas	Daniels,	Nasmyth, Wilson & Co., Ltd., Patricroft, near Manchester.
1888, Jan. 24:	John	Darling,	34 Queen Square, Glasgow.
G. 1881, Mar. 22: / M. 1888, Dec. 18:	David	Davidson,	17 Regent Park Square, Strathbungo, Glasgow.
1861, Dec. 11:	Thomas	Davison,	248 Bath Street, Glasgow.
1869, Feb. 17:	James	Deas,	Engineer, Clyde Trust, Crown Gardens, Glasgow.
1882, Dec. 19:	J. H. L. Van	Deinse	34 Binnenkant, Amsterdam.
1883, Nov. 21:	James	Denholm,	5 Derby Terrace, Sandyford Street, Glasgow.
G. 1883, Dec. 18: / M. 1893, Nov. 21:	William	Denholm,	Meadowside Shipbuilding Yard, Partick, Glasgow.
1888, Feb. 21:	Archibald	Denny,	Braehead, Dumbarton.
1887, Oct. 25:	James	Denny,	Engine Works, Dumbarton.
1895, Apr. 30:	Leslie	Denny,	Leven Shipyard, Dumbarton.
1888, Feb. 21:	Peter	Denny,	Bellfield, Dumbarton.

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1878, Mar. 19:	Frank W.	Dick,	Palmer's Steel Works, Jarrow-on-Tyne.
1890, Nov. 19:	B. Gillespie	Dickson,	c/o J. T. Sellar, 8 Blackfriars Street, Perth.
G 1873, Dec. 24: M. 1878, Jan. 22:	James S.	Dixon,	97 Bath Street, Glasgow.
1895, Feb. 26:	Walter	Dixon,	164 St. Vincent St., Glasgow.
1871, Jan. 17:	William	Dobson,	The Chesters, Jesmond, Newcastle-on-Tyne.
1864, Jan. 20:	James	Donald,	Abbey Works, Paisley.
1892, Nov. 22:	Robert Hanna	Donald,	Abbey Works, Paisley.
1876, Jan. 25:	James	Donaldson,	Almond Villa, Renfrew.
1886, Nov. 23:	Patrick	Doyle, F.R.S.E.,	19 Lall Bazar St., Calcutta.
1890, Apr. 29:	Alexander	Drew,	Francais Morton & Co., Ltd., Garston, near Liverpool.
1895, Mar. 26:	Walter	Drummond,	The Glasgow Railway Engineering Works, Govan, Glasgow.
1884, Dec. 23:	John W. W.	Drysdale,	46 Circus Drive, Glasgow.
1882, Oct. 24:	Chas. R.	Dubs,	Glasgow Locomotive Works, Glasgow.
G. 1886, Nov. 23: M. 1894, Mar. 20:	George F.	Duncan,	Ardenclutha, Port-Glasgow.
1886, Nov. 23:	John	Duncan,	Ardenclutha, Port-Glasgow.
1881, Jan. 25:	Robert	Duncan,	Whitefield Engine Works, Govan, Glasgow.
1873, Apr. 22:	Robert	Dundas, (*Past President.*)	3 Germiston Street, Glasgow.
1869, Nov. 23:	David Jno.	Dunlop, (*Member of Council.*)	Inch Works, Port-Glasgow.
1877, Jan. 23:	John G.	Dunlop,	J. & G. Thomson, Clydebank, Dumbartonshire.
1880, Mar. 23:	Hugh S.	Dunn,	Earlston Villa, Caprington, Kilmarnock.

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1886, Oct. 26:	Peter	Dunn,	1218 Hyde Street, San Francisco, U.S.A.
1883, Oct. 23:	Henry	Dyer, D.Sc., M.A.,	8 Highburgh Terrace, Dowanhill, Glasgow.
1885, Feb. 24:	Francis	Elgar, LL.D., F.R.S.E.,	Fairfield Shipbuilding and Engineering Co., Ltd., 113 Cannon St., London, E.C.
1894, Apr. 24:	Wallace	Fairweather,	62 St. Vincent St., Glasgow.
G. 1869, Nov. 23: / M. 1878, Mar. 19:	John	Ferguson,	Shipbuilder, Leith.
1889, Oct. 22:	Peter	Ferguson,	Phœnix Works, Paisley.
G. 1885, Jan. 27: / M. 1894, Mar. 20:	William D.	Ferguson,	Albert Villa, Ravenhill Road, Belfast.
G. 1881, Feb. 22: / M 1895, Jan. 22:	Wm. R.	Ferguson,	Messrs Barclay Curle & Co., Whiteinch, Glasgow.
1874, Feb. 24:	Immer	Fielden,	2 Thornton Villas, Holderness Road, Hull.
1880, Jan. 27:	Alexander	Findlay,	Parkneuk Iron Works, Motherwell.
G. 1873, Dec. 23: / M. 1884, Nov. 25:	E. Walton	Findlay,	Ardeer, Stevenston.
1884, Dec. 23:	Finlay	Finlayson,	Muirend Cottage, Dundyvan, Coatbridge.
1894, Jan. 23:	Andrew E.	Fleming,	Kandy, Ceylon.
1895, Jan. 22:	Thos.	Fleming,	Atlas Works, Springburn, Glasgow.
1895, Jan. 22:	George L.	Flett,	86 Sussex Street, Paisley Road West, Glasgow.
G. 1869, Oct. 26: / M. 1892, Nov. 22:	F. P.	Fletcher,	46 Buccleuch St., Glasgow.
1883, Dec. 18:	Lawson	Forsyth,	10 Grafton Sq., Glasgow.
1870, Jan. 18:	William	Foulis,	Engineer, Corporation Gas Works, City Chambers, Glasgow.

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1880, Nov. 2: Samson	Fox,	Leeds Forge, Leeds.
1893, Dec. 19: William	Fraser,	11 Bothwell St., Glasgow.
1879, Nov. 25: John	Frazer,	P. Henderson & Co., 15 St. Vincent Place, Glasgow.
1858, Nov. 24: James M. (*Past President; Member of Council, and Honorary Treasurer.*)	Gale,	Engineer, Corporation Water Works, City Chambers, Glasgow.
1893, Jan. 24: William M.	Gale,	18 Huntly Gardens, Kelvinside, Glasgow.
1895, Jan. 22: Charles S.	Galloway,	676 Dumbarton Road, Partick, Glasgow.
1887, Oct. 25: Lewis P.	Garrett,	157 Hope Street, Glasgow.
1888, Mar. 20: Ernest	Gearing,	Fenshurst, Clarence Drive, Harrowgate.
1888, Dec. 18: E. W.	Gemmell,	Board of Trade Offices, 7 York Street, Glasgow.
G. 1873, Dec. 23: / M. 1882, Mar. 21: Andrew	Gibb,	30 South Street, Greenwich, London, S.E.
1886, Nov. 23: Paterson	Gifford,	101 St. Vincent Street, Glasgow.
1859, Nov. 23: Archibald	*Gilchrist,	5 Montgomerie Crescent, Glasgow.
G. 1866, Dec. 26: / M. 1878, Oct. 29: James	Gilchrist,	Stobcross Engine Works, FinniestonQuay, Glasgow.
1894, Nov. 20: Andrew	Gillespie,	34 St. Enoch Sq., Glasgow.
G. 1874, Feb. 24: / M. 1891, Mar. 24: James	Gillespie,	21 Minerva St., Glasgow.
G. 1884, Dec. 23: / M. 1893, Feb. 21: D. C.	Glen,	Ingleston Foundry, Greenock.
1866, Mar. 28: Gilbert S.	Goodwin,	Alexandra Buildings, James Street, Liverpool.
1868, Mar. 11: Joseph	Goodfellow,	3 Towerhill Terrace, Springburn, Glasgow.
1895, Mar. 26: John	Gordon,	152 Craigpark St., Glasgow.

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1882, Apr. 25:	H. Garrett	Gourlay,	Dundee Foundry, Dundee.
G. 1882, Jan. 24: M. 1895, Jan. 22:	A. B.	Gowan,	Naval Construction and Armaments Company, Barrow-in-Furness.
1893, Apr. 25:	David R.	Graham,	Messrs A. Stephen & Son, Engine Department, Linthouse, Govan, Glasgow.
1858, Mar. 12:	George	Graham,	Engineer, Caledonian Railway, Glasgow.
1876, Jan. 25:	Thomas M.	Grant,	11 India Street, Glasgow.
1862, Jan. 8:	James	Gray,	Pathhead Colliery, New Cumnock, Ayrshire.
1881, Dec. 20:	L. John	Groves,	Engineer, Crinan Canal, Ardrishaig.
1881, Jan. 25:	William	Hall,	Shipbuilder, Aberdeen.
G. 1874, Feb. 24: M. 1885, Nov. 24:	Archibald	Hamilton,	New Dock Works, Govan, Glasgow.
G. 1873, Dec. 23: M. 1881, Nov. 22:	David C. *(Member of Council.)*	Hamilton,	Clyde Shipping Co., 21 Carlton Place, Glasgow.
G. 1866, Dec. 26: M. 1873, Mar. 18:	James	Hamilton,	Jun., R. Napier & Sons, Govan.
	John	*Hamilton,	22 Athole Gardens, Glasgow.
G. 1869, Nov. 23: M. 1875, Feb. 23:	J. B.	Hamond,	Sparthfield, Bromley, Kent.
1890, Jan. 21:	Peter	Hampton,	Workman, Clark & Co., Belfast.
G. 1880, Nov. 2: M. 1884, Jan. 22:	Bruce	Harman,	Mossbank Villa, Lenzie.
G. 1874, Feb. 24: M. 1880, Nov. 23:	C. R.	Harvey,	6 Park Quadrant, Glasgow.
1887, Feb. 22:	John H.	Harvey,	Benclutha, Port-Glasgow.
1871, Jan. 17:	William	Hastie,	Kilblain Engine Works, Greenock.
1879, Nov. 25:	A. P.	†Henderson,	30 Lancefield Quay, Glasgow.

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1895, Mar. 26: Fred. N.	Henderson,	Meadowside, Partick, Glasgow.
1888, Dec. 18: J. Bailie	Henderson,	Govt. Hydraulic Engineer, Brisbane, Queensland.
1873, Jan. 21: John	†Henderson,	Meadowside, Partick, Glasgow.
1879, Nov. 25: John L.	†Henderson,	———
1878, Dec. 17: William	Henderson,	Meadowside, Partick, Glasgow.
1870, May 31: Richard	Henigan,	Alma Road, Avenue, Southampton.
G. 1881, Oct. 25: } M. 1887, Oct. 25: }	Charles G. Hepburn,	Consulting Engineer, 169 King Street, Sydney.
1877, Feb. 20: George	Herriot,	Board of Trade Offices, 7 York Street, Glasgow.
1890, Oct. 28: W. Scott	Herriot,	187 Osmaston Rd., Derby.
1892, Nov. 22: Edward P.	Hetherington,	3 Westminster Gdns., Hillhead, Glasgow.
1888, Dec. 18: Wm. Seymour	Hide,	Engine Department, West Cowes, Isle of Wight.
1895, Jan. 22: Thomas	Hill,	3 Whitevale, Dennistoun, Glasgow.
1880, Nov. 2: Charles P. *(Member of Council.)*	Hogg,	175 Hope Street, Glasgow.
1883, Mar. 20: John	Hogg,	Victoria Engine Works, Airdrie.
1880, Mar. 23: F. G.	Holmes,	Burgh Surveyor, Stirling.
1883, Mar. 20: Matthew *(Member of Council.)*	Holmes,	Netherby, Lenzie.
1894, Apr. 24: A. Campbell	Holms,	Lloyd's Register, 2 Whitelion Court, Cornhill, London.
1890, Mar. 25: Colin	†Houston,	Harbour Engine Works, 60 Portman Street, Glasgow.
1888, Mar. 20: Robert	Houston,	———

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Original:	James	Howden,	8 Scotland Street, Glasgow.
1891, Dec. 22:	James Howden	Hume,	38 Keir St., Pollokshields, Glasgow.
Original:	Edmund	*Hunt,	87 St. Vincent St., Glasgow.
G. 1886, Oct. 26: / M. 1889, Nov. 19:	Gilbert M.	Hunter,	Town Engineer, New Amsterdam, Berbice, British Guiana.
1881, Jan. 25:	James	Hunter,	Aberdeen Iron Works, Aberdeen.
1891, Feb. 24:	Joseph Gilbert	Hunter,	342 Argyle Street, Glasgow.
1895, Mar. 26:	James H.	Hutchison,	Shipbuilder, Port-Glasgow.
G. 1873, Dec. 23: / M. 1885, Nov. 24:	Guybon	Hutson,	Kelvinhaugh Engine Works, Glasgow.
1893, Mar. 21:	Guybon	Hutson, Jr.,	Kelvinhaugh Engine Works, Glasgow.
1861, May 1:	John *(President.)*	Inglis,	Point House Shipyard, Glasgow.
G. 1883, Jan. 23: / M. 1891, Nov. 24:	J. Anthony	Inglis,	10 Kingsborough Gardens, Kelvinside, Glasgow.
1891, Apr. 28:	William	Inglis,	Lochside House, Hamilton.
1890, Feb. 25:	William	Ireland,	7 Ardgowan Terrace, Glasgow.
1893, Nov. 21:	Alexander	Jack,	Dellburn Works, Motherwell.
1891, Mar. 24:	Peter	Jackson,	Consulting Engineer, 67 Hope Street, Glasgow.
1875, Dec. 21:	William	Jackson,	Govan Engine Works, Govan, Glasgow.
1889, Mar. 26:	Prof. Andw. *(Member of Council.)*	Jamieson,	F.R.S.E., The Glasgow and West of Scotland Technical College, Bath St., Glasgow.
1892, Oct. 25:	Llewellen	Jones,	Plantation Non Pareil, Demerara.
1891, Oct. 27:	Andrew	Johnston,	Bank Buildings, Hong Kong.

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1879, Feb. 25:	David	Johnston,	Eden Villa, Govan, G'gow.
1883, Jan. 23:	F. C.	Kelson,	AngraBank,WaterlooPark, Waterloo, Liverpool.
G. 1883, Feb. 20: M. 1892, Oct. 25:	Ebenezer D.	Kemp,	25 Grove Road, Rockferry, Birkenhead.
1875, Nov. 23:	William	Kemp,	49 Jamaica St., Glasgow.
1895, Apr. 30:	Alex. M'A.	Kennedy,	Rosslea, Dumbarton.
1877, Jan. 23:	John	Kennedy,	R. M'Andrew & Co., Suffolk House, Laurence Pountney Hill, London, E.C.
1891, Dec. 22:	Rankin	Kennedy,	Clifton Villas, 1 Camden Square, London.
1876, Feb. 22:	Thomas	Kennedy,	Water Meter Works, Kilmarnock.
1894, Apr. 24:	William	Kennedy,	13 Victoria Cres., Dowanhill, Glasgow.
1894, Nov. 20:	Archibald	Kerr,	2 Kelvinside Gars., Glasgow.
1890, Jan. 21:	Alexander	Kidd,	342 Argyle St., Glasgow.
1893, Feb. 21:	John	King,	Tigh Ruadh, Possilpark, Glasgow.
G. 1886. Dec. 21: M. 1894, Mar. 20:	Donald	King,	22 Rothesay Gardens, Partick, Glasgow.
1895, Mar. 26:	J. Foster	King,	The British Corporation, 69 St. Vincent St., Glasgow.
1879, Dec. 23:	John G.	Kinghorn,	Tower Buildings, Water Street, Liverpool.
1885, Nov. 24:	Frank E.	†Kirby,	Detroit, U.S., America.
Original:	David	*Kirkaldy,	Testing and Experimenting Works, 99 Southwark Street, London, S.E.
1885, Jan. 27:	Charles A.	Knight,	21 Bothwell Street, Glasgow.
1880, Mar. 23:	Frederick	Krebs,	18 Fredericiagade, Copenhagen, Denmark.

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1891, Jan. 27:	James A.	Lade,	Glenburn Villa, Port-Glasgow.
1884, Mar. 25:	John	Laidlaw,	98 Dundas Street, S.S., Glasgow.
1862, Nov. 26:	Robert	Laidlaw,	147 East Milton Street, Glasgow.
1880, Mar. 20:	Andrew	Laing,	5 Oswald Gardens, Scotstounhill, Glasgow.
1875, Oct. 26:	William	Laing,	17 M'Alpine St., Glasgow.
1880, Feb. 24:	James	Lang,	°/₀ George Smith & Sons, City Line, 75 Bothwell Street, Glasgow.
1884, Feb. 26:	John	Lang, Jun.,	Church Street, Johnstone.
1888, Feb. 21:	George B.	Laurence,	Clutha Iron Works, Paisley Road, Glasgow.
1893, Apr. 25:	Jas. T. G.	Leslie,	21 Kelvingrove St., Glasgow.
1891, Feb. 24:	William	Leslie,	28 Wilton Gardens, Glasgow.
G. 1873, Dec. 23: M. 1876, Oct. 24:	Charles C.	Lindsay,	167 St. Vincent St., Glasgow.
1893, Feb. 21:	William T.	Lithgow,	Port-Glasgow.
1884, Feb. 26:	John	List,	3 St. John's Park, Blackheath, London, S.E.
1862, Apr. 2:	H. C.	Lobnitz,	Renfrew.
1889, Dec. 17:	Alfred E.	Lonergan,	Whitefield Engine Works, Govan, Glasgow.
1888, Feb. 21:	Hugh D.	Lusk,	Rosebank, Greenock.
1885, Oct. 27:	John	Lyall,	69 St. Vincent Crescent, Glasgow.
1858, Feb. 17:	David	M'Call,	160 Hope Street, Glasgow.
1874, Mar. 24:	Hector	MacColl,	Strandtown, Belfast.
	Hugh	*MacColl,	Manager, Wear Dock Yard, Sunderland.
G. 1881, Dec. 20: M. 1889, Oct. 22:	Hugo	MacColl,	Wreath Quay Engineering Works, Sunderland.

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1883, Oct. 23: James	M'Creath,	208 St. Vincent Street, Glasgow.
1871, Jan. 17: David	M'Culloch,	Vulcan Works, Kilmarnock.
1891, Jan. 27: Frank	M'Culloch,	Chief Builder, Her Majesty's Royal Indian Marine Dockyard, Bombay.
1884, Feb. 26: James	M'Ewan,	Cyclops Foundry, 50 Peel Street, London Road, Glasgow.
1891, Jan. 27: Joseph	M'Ewan,	35 Houldsworth St., Glasgow.
G. 1874, Feb. 24: George M. 1885, Nov. 24:	M'Farlane,	121 West George St., Glasgow.
1880, Nov. 2: James W.	Macfarlane,	12 Balmoral Villas, Cathcart, Glasgow.
1886, Oct. 26: Walter	Macfarlane,	12 Lynedoch Cres., Glasgow.
G. 1886, Dec. 21: J. Grant M. 1891, Apr. 28:	M'Gregor,	Canadian Pacific Railway Engineering Department, Montreal.
1886, Jan. 26: Thomas	M'Gregor,	10 Mosesfield Terrace, Springburn, Glasgow.
1894, Feb. 20: Donald	M'Intosh,	Dunglass, Bowling.
1887, Nov. 22: Hugh	M'Intyre,	128 Victoria St., Partick, Glasgow.
1887, Apr. 6: Edward	Mackay,	8 George Square, Greenock.
1893, Apr. 25: John	M'Kenzie,	128 South Portland Street, Glasgow.
1881, Mar. 22: William A.	Mackie,	Falkland Bank, Partickhill, Glasgow.
G. 1882, Dec. 19: Allan M. 1894, Mar. 20:	M'Keand,	17 Queen Margaret Drive, Kelvinside, Glasgow.

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1888, Apr. 24:	James	M'Kechnie,	Engine Department, Astilleros del Nervion, Bilbao, Spain.
1892, Feb. 23:	John F.	MacLaren, B.Sc.,	Eglinton Foundry, Canal Street, Glasgow.
J. 1880, Nov. 2: M. 1885, Dec. 22:	Robert	MacLaren,	Eglinton Foundry, Canal Street, Glasgow.
1891, Apr. 28:	Prof. Alex.	MacLay, B.Sc.,	Clairinch, Milngavie.
	Sir Andw.	*Maclean,	Viewfield House, Partick, Glasgow.
1886, Dec. 21:	William T.	†Maclellan,	Clutha Iron Works, G'gow.
1890, Feb. 25:	Robert	M'Master,	Linthouse, Glasgow.
	William	*MacMillan,	1 Foremount Ter., Partick, Glasgow.
1884, Dec. 23:	John	M'Neil,	Helen St., Govan, Glasgow.
1894, Nov. 20:	John	Macpherson,	5 Holland Place, Glasgow.
1891, Mar. 24:	William	M'Whirter,	1 Osbourne Place, Govan.
1895, Jan. 22:	David	Marshall,	Glasgow Tube Works, Glasgow.
1875, Dec. 21:	George	Mathewson,	Bothwell Works, Dunfermline.
1895, Jan. 22:	Robert C.	Mathewson,	Glenburn Iron Works, Greenock.
1884, Apr. 22:	Henry A.	Mavor, (*Vice-President.*)	57 West Nile St, Glasgow.
1894, Nov. 20:	Sam	Mavor,	3 Elmbank Cres., Glasgow.
1876, Jan. 25:	William W.	May,	5 Edelweiss Terrace, Partickhill, Glasgow.
1887, Jan. 25:	Henry	Mechan,	13 Montgomerie Quadrant, Glasgow.
1891, Oct. 27:	Samuel	Mechan,	5 Kelvingrove Terrace, Glasgow.
G. 1876, Oct. 24: M. 1882, Nov. 28:	James	Meldrum,	3 Elmbank Street, Glasgow.

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1883, Jan. 23:	William	Melville,	Engineer, Glasgow & South-Western Railway, St. Enoch Square, Glasgow.
1881, Mar. 22:	William	Menzies,	7 Dean Street, Newcastle-on-Tyne.
G. 1882, Jan. 24: / M. 1890, Oct. 28:	R. A.	Middleton,	23 Kensington Terrace, Ibrox, Glasgow.
G. 1873, Dec. 23: / M. 1881, Nov. 22:	John F.	Miller,	Greenoakhill, Broomhouse.
Original:	James B.	Mirrlees,	45 Scotland St., Glasgow.
1886, Jan. 26:	Alexander	Mitchell,	Hayfield House, Springburn.
1888, Nov. 20:	Thomas	Mitchell,	284 Maxwell Road, Pollokshields, Glasgow.
1876, Mar. 21:	James	Mollison, (*Member of Council.*)	6 Hillside Gardens, Partickhill.
1869, Dec. 21:	John	Montgomerie,	210 Great Northern Ter., Possilpark, Glasgow.
1883, Nov. 21:	Joseph	Moore,	Fairhope, Byne Road, Sydenham, Kent.
1862, Nov. 26:	Ralph	Moore,	13 Clairmont Gardens, Glasgow.
1891, Jan. 27:	Robert T.	Moore, B.Sc.,	13 Clairmont Gardens, Glasgow.
1888, Mar. 20:	William	Morison,	41 St. Vincent Crescent, Glasgow.
G. 1878, Dec. 17: / M. 1883, Jan. 23.	Robert	Morton,	21 Bothwell St., Glasgow.
1892, Feb. 23:	Robert	Motion,	J. & P. Coats, Paisley.
1885, Mar. 24:	Edmund	Mott,	Board of Trade Surveyor, 7 York Street, Glasgow.
1891, Nov. 24:	Montague B.	Mountain,	4 Regent Terr., Newcastle-on-Tyne.
1864, Feb. 17:	Hugh	Muir,	7 Kelvingrove Terrace, Glasgow.
1882, Jan. 24:	John G.	†Muir,	———

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1882, Dec. 19: Robert D. Munro, Engineer, Scottish Boiler Insurance Co., 13 Dundas Street, Glasgow.

Original: James Murdoch, Shipbuilder, Port-Glasgow.

1880, Jan. 27: William Murdoch, ———

G. 1878, May 14: } Angus Murray, Strathray, Dumbreck.
M. 1889, Nov. 19: }

1886, Jan. 26: James Murray, 94 Washington St., G'gow.

1892, Feb. 23: Robert Murray, 28 Waterhouse Lane, Hull.

1891, Dec. 22: Thos. Blackwood Murray, B.Sc., 20 Balmoral Crescent, Queen's Park, Glasgow.

1881, Jan. 25: Henry M. Napier, Shipbuilder, Yoker, near Glasgow.

1857, Dec. 23: John †*Napier, C. Audley Mansions, Grosvenor Square, London.

1881, Dec. 20: Robert T. †Napier, Shipbuilder, Yoker, near Glasgow.

1891, Oct. 27: Walter Neilson, Clydebridge Steel Works, Cambuslang.

1883, Dec. 18: Thomas Nicol, 6 Rosevale Terrace, Partick, Glasgow.

1884, Dec. 23: Wm. H. Nisbet, c/o Dr Hood, 291 Elizabeth Street, Sydney, N.S.W.

1887, Apr. 6: William Nish, Anchor Line Offices, 7 Bowling Green, New York.

1876, Dec. 19: Richard Niven, Airlie, Ayr.

1861, Dec. 11: John Norman, 131A St. Vincent Street, Glasgow.

1891, Jan. 27: William O'Brien, 21 Ibrox Terrace, Govan, Glasgow.

1882, Jan. 24: Robert S. Oliver, Highland Railway Co., Inverness.

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1860, Nov. 28:	John W.	Ormiston,	Douglas Gardens, Uddingston.
1885, Mar. 24:	Alex. T.	Orr,	Fletcher & Co., Tilbury Docks, Essex.
1890, Oct. 28:	Heinrich	Paasch,	27 Rue d'Amsterdam, Antwerp.
1883, Nov. 21:	W. L. C.	Paterson,	19 St. Vincent Crescent, Glasgow.
G. 1879, Nov. 25: M. 1894, Nov. 20:	Alex. R.	Paton,	Redthorn, Partick, Glasgow.
1887, Nov. 22:	Prof. George	Paton,	Royal Agricultural College, Cirencester.
1889, Feb. 26:	John	Paton,	299 Shields Road, Pollokshields, Glasgow.
1895, Jan. 22:	Alex. W.	Pattie,	University Gardens Terrace, Hillhead, Glasgow.
1877, Apr. 24:	Andrew	Paul,	Levenford Works, Dumbarton.
G. 1884, Feb. 26: M. 1886, Dec. 21:	Matthew	Paul, Jun.,	Levenford Works, Dumbarton.
1880, Nov. 2:	James M.	Pearson,	John Dickie St., Kilmarnock.
1894, Dec. 18:	James D.	Peat,	Finnieston Quay, Glasgow.
G. 1873, Dec. 23: M. 1888, Oct. 23:	Edward C.	Peck,	Yarrow & Co., Poplar, London.
G. 1881, Oct. 25: M. 1891, Oct. 27:	Wm. T.	Philp,	Workman, Clark & Co., Belfast.
1887, Oct. 25:	Robt. Band	Pope,	Leven Shipyard, Dumbarton.
1877, Nov. 20:	F. P.	Purvis,	Don Villa, Gourock.
1868, Dec. 23:	Henry M.	Rait,	155 Fenchurch Street, London.
1873, Apr. 22:	Richard	Ramage,	Shipbuilder, Leith.
1872, Oct. 22:	David	Rankine,	5 W. Regent St., Glasgow.

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1886, Mar. 23:	John F.	Rankin,	Eagle Foundry, Greenock.
G. 1880, Nov. 2: M. 1894, Mar. 20:	Matthew	Rankin,	Fassoula Iron Works, Smyrna.
G. 1886, Dec. 21: M. 1894, Dec. 18:	Andrew T.	Reid,	Hydepark Loco. Works, Glasgow.
1881, Jan. 25:	Charles	Reid,	Lilymount, Kilmarnock.
1883, Nov. 21:	George W.	Reid,	Locomotive Dept., Natal Govt. Railways, Durban, Natal, South Africa.
1869, Mar. 17:	James	Reid,	Shipbuilder, Port-Glasgow.
1891, Nov. 24:	James B.	†Reid,	Chapelhill, Paisley.
G. 1886, Dec. 21: M. 1894, Dec. 18:	John	†Reid,	Hydepark Loco. Works, Glasgow.
G. 1873, Dec. 23: M. 1881, Nov. 22:	Charles H.	Reynolds,	Sir W. G. Armstrong, Mitchell & Co., Walker Shipyard, Newcastle-on-Tyne.
1886, Apr. 27:	James	Riley,	Glasgow Iron and Steel Co., Limited, 168 St. Vincent Street, Glasgow.
1890, Mar. 25:	James W.	Robb,	15 Huntly Terrace, Shettleston.
1876, Oct. 24:	Duncan	Robertson,	Baldroma, Ibrox, Glasgow.
1884, Apr. 22:	R. A.	Robertson,	8 Park Circus Place, Glasgow.
1863, Nov. 25:	William	Robertson,	123 St. Vincent Street, Glasgow.
1888, Apr. 24:	J. F.	Robinson,	Atlas Works, Springburn, Glasgow.
Original:	Hazltn. R.	*Robson, (*Past President.*)	14 Royal Cresct., Glasgow.
1893, Mar. 21:	Anderson	Rodger,	Glenpark, Port-Glasgow.
G. 1882, Nov. 28: M. 1891, Oct. 27:	J. MacEwan	Ross,	Ardenlea, Lenzie.
1861, Dec. 11:	Richard G.	Ross,	21 Greenhead St., Glasgow.
1892, Jan. 26:	Fred. John	Rowan,	121 West Regent Street, Glasgow.

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Original:	David	*Rowan, (*Past President.*)	231 Elliot Street, Glasgow.
G. 1875, Dec. 21: M. 1885, Jan. 27:	James	Rowan, (*Vice-President.*)	231 Elliot Street, Glasgow.
1888, Dec. 18:	Thomas	Rowley,	Board of Trade Offices, Virginia St., Greenock.
G. 1858, Dec. 22: M. 1863, Mar. 4:	George	Russell, (*Vice-President.*)	Engineer, Motherwell.
1881, Feb. 22:	Joseph	Russell,	Shipbuilder, Port-Glasgow.
1890, Jan. 21:	Edward Mowbray	Salmon,	2 White Lion Court, Cornhill, London, E.C.
1876, Oct. 24:	Peter	Samson,	Board of Trade Offices, Bedford St., Covent Garden, London, W.C.
1885, Feb. 24:	James	Samuel, Jun.,	185 Kent Road, Glasgow.
1883, Feb. 20:	John	Sanderson,	Lloyd's Register, 342 Argyle Street, Glasgow.
1892, Oct. 25:	Wm. Brooks	Sayers,	Glenwood, Bearsden.
G. 1879, Mar. 25: M. 1888, Oct. 23:	John	†Scobie,	c/o Sen. Pouchard, M'Taggart, Lother, & Co., F.C. de Autioquia, Puerto Berrio Ria Magdalena, U. S. of Columbia.
1893, Apr. 25:	James	Scott,	Yloilo, Philippine Islands.
1872, Jan. 30:	James E.	Scott,	52 Coal Exchange, London.
1881, Jan. 25:	John	Scott,	Abden Works, Kinghorn.
1893, Nov. 21:	John	Scott,	Engineer, New Zealand Refrigeration Company, Omaru, N.Z.
1860, Nov. 28:	Thos. B.	*Seath,	42 Broomielaw, Glasgow.
1875, Jan. 26:	Alexander	Shanks,	Belgrade, Aytoun Road, Pollokshields, Glasgow.

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1892, Apr. 26: Alexander	Shanks, Jun.,	Eastwood Engine Works, Pollokshaws, Glasgow.
1895, Apr. 30: Edmund	Sharer,	8 Belhaven Cres., Glasgow.
1889, Mar. 26: John W.	Shepherd,	Carrickarden, Bearsden.
1858, Nov. 24: William	Simons,	Tighnabruaich, Argyleshire.
1862, Jan. 22: Alexander	Simpson,	175 Hope Street, Glasgow.
1887, Jan. 25: Robert	Simpson, B.Sc.,	175 Hope St., Glasgow.
G. 1877, Mar. 20: / M. 1887, Dec. 20: \ Nisbet	Sinclair,	The Wm. Cramp & Sons' Ship and Engine Building Co., Philadelphia, U.S.A.
G. 1884, Mar. 25: / M. 1891, Mar. 24: \ Russell	Sinclair,	Consulting Engineer, 97 Pitt St., Sydney, N.S.W.
G. 1882, Nov. 28: / M. 1889, Oct. 22: \ Geo. H.	Slight, Jun.,	c/o Jas. Slight, 131 West Regent Street, Glasgow.
1880, Nov. 2: Alexander D.	Smith,	5 Belmar Terrace, Shields Road, Pollokshields, Glasgow.
1871, Dec. 11: Hugh	Smith,	9 Kelvinside Terrace, N., Glasgow.
1888, Oct. 23: James	Smith,	Orange Grove Estate, Tacarigua, Trinidad, B.W.I.
1892, Nov. 22: William	Smith,	Eglinton Engine Works, Glasgow.
1870, Feb. 22: Edward	Snowball,	Engineer, Hyde Park Locomotive Works, Springburn, Glasgow.
1887, Jan. 25: Peter A.	Somervail,	Dalmuir Ironworks, Dalmuir.
1883, Dec. 18: Alex. E.	†Stephen,	9 Princes Gardens, Dowanhill, Glasgow.
1895, Apr. 30: Fred. J.	†Stephen,	Linthouse, Govan, Glasgow.
John	†*Stephen,	Linthouse, Govan, Glasgow.
1894, Jan. 23: William	Steven,	18 Sandyford Place, Glasgow.

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1894, Jan. 23: Alex. W. Stewart, Crescent, Dalmuir.
1890, Feb. 25: Andrew Stewart, 41 Oswald St., Glasgow.
1867, Jan. 30: Duncan Stewart, 47 Summer Street, Glasgow.
1890, Mar. 25: James †Stewart, Harbour Engine Works, 60 Portman Street, Glasgow
1892, Mar. 22: John Graham Stewart, B.Sc., 17 Park Terrace, Glasgow.
1874, Oct. 27: Peter Stewart, 53 Renfield Street, Glasgow.
G. 1873, Dec. 23: } W. B. Stewart, 10 Buckingham Terrace,
M. 1882, Oct. 24: } Hillhead, Glasgow.
Original: Patrick Stirling, The Great Northern Railway, Doncaster.
1893, Apr. 25: C. E. Stromeyer, Lloyd's Register, 342 Argyle Street, Glasgow.
1889, Oct. 22: James Stuart, 115 Wellington St., Glasgow.
1877, Jan. 23: James Syme, 8 Glenavon Ter., Partick, Glasgow.

1879, Oct. 28: James Tait, County Buildings, Wishaw.
1885, Apr. 28: Peter Taylor, Dock Shipbuilding Yard, Port-Glasgow.
1879, Mar. 25: Staveley Taylor, Russell & Co., Shipbuilders, Greenock.
1885, Jan. 27: George W. Thode, 21 Bothwell Street, Glasgow.
1889, Feb. 26: John Thom, 93 Hope Street, Glasgow.
1887, Apr. 26: Prof. Arthur W. Thomson, D.Sc., College of Science, Poona, India.
1893, Oct. 24: G. Caldwell Thomson, 18 Mühlen Strasse, Riga, Russia.
1882, Apr. 25: Geo. P. Thomson, Clydebank, Dumbartonshire.
1883, Dec. 18: George Thomson, 9 Buckingham Ter., Partick, Glasgow.

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G. 1874, Feb. 24: M. 1889, Oct. 22:	George C.	Thomson,	23 Kersland Terrace, Hillhead, Glasgow.
G. 1880, Nov. 23: M. 1894, Nov. 20:	George	Thomson,	35 Marchmont Crescent, Edinburgh.
1886, Mar. 23:	James	Thomson, M.A.,	22 Wentworth Place, Newcastle-on-Tyne.
1868, Feb. 12:	James M.	Thomson,	75 Bothwell St., Glasgow.
1882, Mar. 21:	James R.	Thomson,	Clydebank, Dumbartonshire
1868, May 20:	John	Thomson,	3 Crown Terrace, Dowanhill, Glasgow.
1895, Feb. 26:	R. H. B.	Thomson,	Govan Shipbuilding Yard, Govan, Glasgow.
1864, Feb. 17:	W. R. M.	Thomson,	96 Buchanan St., Glasgow,
1878, May 14:	W. B.	Thompson,	Ellengowan, Dundee.
G. 1887, Jan. 25: M. 1892, Oct. 25:	David R.	Todd,	122 Bedford Street, Liverpool.
1876, Nov. 21:	Alexander	Turnbull,	St. Mungo's Works. Bishopbriggs, Glasgow.
1875, Nov. 23:	John	Turnbull, Jun.,	Consulting Engineer, 18 Blythswood Sq., Glasgow.
1892, Jan. 26:	John	Wallace,	12 Kelvingrove Street, Glasgow.
1883, Jan. 23:	Peter	Wallace,	Ailsa Shipbuilding Co. Troon.
1885, Mar. 24:	W. Carlile (*Member of Council.*)	Wallace,	Castle Shipyard, Port-Glasgow.
1886, Jan. 26:	John	Ward,	Leven Shipyard, Dumbarton.
1893, Dec. 19:	Prof. W. H.	Watkinson,	24 Albion Crescent, Dowanhill, Glasgow.
1875, Mar. 23:	G. L.	Watson,	108 W. Regent Street, Glasgow.
1864, Mar. 16:	Sir W. Renny	Watson,	16 Woodlands Ter., G'gow.
G. 1875, Dec. 21: M. 1886, Oct. 26:	R. G.	Webb,	Richardson & Cruddas, Byculla, Bombay.

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G. 1878, Dec. 17: M. 1887, Nov. 22:	Prof. R. L.	Weighton, M.A.,	Durham College of Science, Newcastle-on-Tyne.
1874, Dec. 22:	George	Weir,	18 Millbrae Cres., Langside, Glasgow.
1874, Dec. 22:	James	Weir,	Holmwood, 72 St. Andrew's Drive, Pollokshields.
G. 1876, Dec. 19: M. 1884, Feb. 26:	Thomas D.	Weir,	Towerhill, Kilmaurs.
1889, Apr. 23:	Thomas	†Weir,	China Merchants' Steam Navigation Co., Marine Superintendent's Office, Shanghai, China.
1869, Feb. 17:	Thomas M.	Welsh,	3 Princes Gardens, Dowanhill, Glasgow.
1868, Dec. 23:	Henry H.	West,	5 Castle Street, Liverpool.
1883, Feb. 20:	Richard S.	White,	Craigmont, Pollokshields, Glasgow.
1888, Mar. 20:	George	Whitehall,	c/o Walsh, Lovett, & Co., Bombay.
1887, Apr. 6:	James	Whitehead,	6 Buchanan Ter., Paisley.
G. 1877, Jan. 23: M. 1890, Oct. 28:	Robt. John	Wight,	61 Brighton Road, Stoke Newington, London, N.
1884, Nov. 25:	John	Wildridge,	Consulting Engineer, Sydney, N.S.W., Australia.
1876, Oct. 24:	Francis W.	Willcox,	45 West Sunniside, Sunderland.
1884, Dec. 23:	James	Williamson,	Director H.M. Dockyards, Whitehall, London.
1883, Feb. 20:	Robert	Williamson,	Lang & Williamson, Engineers, &c., Newport, Mon.
1890, Dec. 23:	Robert	Williamson,	Pott, Cassels & Williamson, Motherwell.
	Alex. H.	*Wilson,	Aberdeen Iron Works, Aberdeen.

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1887, Oct. 25:	David	Wilson,	Arecibo, Porto Rico, West Indies.
1889, Oct. 22:	Gavin	Wilson,	16 Robertson St., Gl'gow.
1868, Dec. 23:	James	Wilson,	Engineer, Corporatn. Water Works, Edinburgh.
1870, Feb. 22:	John	Wilson,	165 Onslow Drive, Dennistoun, Glasgow.
G. 1883, Jan. 29: / M. 1891, Feb. 24:	John	Wilson,	29 Waterloo St., Glasgow.
1895, Apr. 30:	William	Wilson,	Lilybank Boiler Works, Glasgow.
1858, Jan. 20:	Thomas	†*Wingate,	Viewfield, Partick, G'gow.
1891, Feb. 24:	Thos. Wm.	Wray,	Victoria Place, Knottingley, Yorkshire.
1890, Mar. 25:	William G.	Wrench,	27 Oswald St., Glasgow.
1867, Nov. 27:	John	Young,	Galbraith Street, Stobcross, Glasgow.
G. 1888, Jan. 24: / M. 1894, Jan. 23:	J. Denholm	Young,	West India House, 96 Leadenhall St., London, E.C.
1894, Mar. 20:	Thomas	Young,	58 Renfield St., Glasgow.
1895, Mar. 26:	Wm. And.	Young,	Millburn House, Renfrew.

ASSOCIATES.

	Thomas	*Aitken,	8 Commercial Street, Leith.
1888, Nov. 20:	Capt. John	Bain,	4 Edelweiss Ter., Partick, Glasgow.
1883, Oct. 28:	John	Barr,	Secretary, Glenfield Co., Kilmarnock.

Names marked thus * were Associates of Scottish Shipbuilders' Association at incorporation with Institution, 1865.

Names marked thus † are Life Associates.

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1882, Dec. 19: William	Begg,	Sheriff Park, Rutherglen.
1884, Dec. 23: W. S. C.	Blackley,	70 Wellington St., Glasgow.
1876, Jan. 25: John	†Brown, B.Sc.,	11 Somerset Place, Glasgow.
1865, Jan. 18: John	Bryce,	Sweethope Cottage, N. Milton Road, Dunoon.
1880, Dec. 21: John	Cassells,	Hazel Bank, 62 Glencairn Drive, Pollokshields, Glasgow.
1893, Feb. 21: William	Cassels,	Cairndhu, 12 Newark Drive, Pollokshields, Glasgow.
1895, Jan. 22: A. L.	Claussen,	118 Broomielaw, Glasgow.
1885, Feb. 24: Robert	Darling,	4 West George Street, Glasgow.
1895, Mar. 26: Walter L.	Fisher,	Glenburn Ironworks, Greenock.
1863, Mar. 18: Robert	Gardner,	136 George Street, G'gow.
1891, Oct. 27: James	Galloway, Jun.,	Whitefield Works, Govan.
1860, Jan. 18: George T.	Hendry,	79 Gt. Clyde St., Glasgow.
1895, Jan. 22: John	Hunter,	101 Armadale St., Glasgow.
1882, Oct. 24: Wm. A.	Kinghorn,	81 St. Vincent St., Glasgow.
1884, Feb. 26: C. R. L.	Lemkes,	194 Hope Street, Glasgow.
1892, Nov. 22: Alexander	M'Ara,	65 Morrison St., Glasgow.
1895, Mar. 26: Lawrence	MacBrayne,	11 Park Circus Pl., Glasgow.
1893, Jan. 24: T. W.	M'Intyre,	123 Hope Street, Glasgow.
1893, Feb. 21: William	M'Kinnel,	Clyde Steel and Iron Works, Sheffield.
1886, Jan. 26: Capt. Dun.	M'Pherson,	3 Cecil Street, Paisley Rd., W., Glasgow.

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1874, Mar. 24:	James B.	Mercer,	Broughton Copper Works, Manchester.
	James S.	*Napier,	33 Oswald Street, Glasgow.
1889, Jan. 22:	William	Rigg,	3 Grantly Place, Shawlands, Glasgow.
1894, Mar. 20:	Thomas A.	Ross,	Glenwood, Bridge-of-Weir.
1888, Jan. 24:	Samuel	Smillie,	71 Lancefield St., Glasgow.
1876, Jan. 25:	George	Smith,	75 Bothwell St., Glasgow.
	H. J.	*Watson,	5 Oswald Street, Glasgow.
1892, Jan. 26:	Alexander	Young,	53 Waterloo St., Glasgow.
1882, Dec. 19:	John D.	Young,	Scottish Boiler Insurance Co., 13 Dundas Street, Glasgow.
	William	*Young,	Galbraith Street, Stobcross, Glasgow.

GRADUATES.

1882, Nov. 28:	William H.	Agnew,	The Royal Shipbuilding and Engineering Company, Flushing, Holland.
1888, Jan. 24:	H. Wallace	Aitken,	Netherlea, Pollokshields, Glasgow.
1888, Jan. 24:	James	Allan,	144 Buccleuch St., Glasgow.
1893, Mar. 21:	Lawrence	Anderson,	2 Windsor Quadrant, Kelvinside, Glasgow.
1888, Oct. 23:	Donald S.	Arbuthnot,	c/o Charles Brand & Son, 172 Buchanan Street, Glasgow.

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1890, Dec. 23: Arthur S. D.	Arundel,	Penn St. Works, Hoxton, London, N.
1892, Jan. 26: Peter	Bain,	54 Glasgow Road, Dumbarton.
1894, Mar. 20: Fred. W.	Baker,	149A Tremont St., Boston, U.S.A.
1888, Apr. 24: Harry D. D.	Barman,	2 Gilmour Street, Byres Road, Glasgow.
1892, Nov. 22: Edmund G.	Baxter,	Caledonian Railway, 3 Germiston Street, Glasgow.
1885, Dec. 22: Peter M'L.	Baxter,	Chief Mechanical Engineer, Rio Tinto, Huelva, Spain.
1887, Apr. 26: Thomas	Bell,	8 Lawrence Place, Partick, Glasgow.
1894, Feb. 20: John H.	Bell,	29 Bentinck St., Glasgow.
1894, Mar. 20: Richard	Bell,	17 Minerva St., Glasgow.
1885, Mar. 24: Alexander	Bishop,	3 Germiston Street, Glasgow.
1892, Oct. 25: John	Black,	7 Huntly Ter., Kelvinside, Glasgow.
1885, Oct. 27: Archibald	Blair,	48 Overnewton St., Glasgow.
1891, Oct. 27: Archibald	Blair, Jun.,	7 Corunna Street, Glasgow.
1892, Mar. 22: Frank R.	Blair,	232 Renfrew St., Glasgow.
1884, Jan. 22: George	Blair, Jun.,	4 Kinnoul Place, Dowanhill, Glasgow.
1885, Oct. 27: William C.	Borrowman,	53 Bentinck St., Glasgow.
1894, Nov. 20: Robert	Bowie,	156 St. Vincent St., Glasgow.
1891, Dec. 22: W. D.	Bowman,	102 Hill Street, Garnethill, Glasgow.
1888, Jan. 24: Mark	Brand, B.Sc.,	Barrhill Cottage, Twechar, Kilsyth.
1888, Mar. 20: James	Brown,	San Nicholas del Puerto, Sevilla, Spain.
1894, Dec. 18: J. Pollock	Brown,	2 Park Grove Ter., Glasgow.

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1893, Oct. 24: Johannes	Bruhn,	1 University Place, Partick, Glasgow.
1891, Jan. 27: Walter G.	Buchanan,	17 Sandyford Pl., Glasgow.
1891, Feb. 24: Bertram W.	Burnside,	4 Gourlay Street, Springburn, Glasgow.
1890, Jan. 21: William	Caird,	25 Woodside Quadrant, Glasgow.
1891, Feb. 24: John	Calder,	1 Iona Place, Mt. Florida, Glasgow.
1891, Jan. 27: Hugh	Caldwell,	The Braes, by Kilbarchan.
1892, Oct. 25: Hugh	Cameron,	40 Gardner Street, Partick, Glasgow.
1888, Jan. 24: Angus	Campbell,	9 John St., Southampton.
1890, Dec. 23: Wm. H.	Carslaw, Jun.,	Parkhead Boiler Works, Parkhead.
1890, Oct. 28: Robert D.	Cassells,	62 Glencairn Drive, Pollokshields, Glasgow.
1884, Feb. 26: John	Cleland, B.Sc.,	Woodhead Cottage, Old Monkland.
1893, Apr. 25: W. A.	Cleland,	Yloilo, Philippine Islands.
1891, Oct. 27: James	Cochrane,	Normal College, Capetown.
1884, Feb. 26: Alexander	Conner,	9 Scott Street, Glasgow.
1885, Dec. 22: Benjamin	Conner,	9 Scott Street, Glasgow.
1885, Oct. 27: Francis	Coutts,	25 Roslin Ter., Aberdeen.
1892, Feb. 23: George H.	Cox,	———
1892, Dec. 20: James	Craig,	35 Gardner Street, Partick, Glasgow.
1894, Nov. 20: James	Craig,	14 Bridge Street, Glasgow.
1890, Oct. 28: John G.	Crookston,	— ———
1886, Mar. 23: Thomas	Danks,	——— -
1888, Dec. 18: Harry L.	Davies,	The Vicarage, Kirkby-Lonsdale, England.

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1891, Dec. 22: Kristian S.	Dekke,	Bergen, Norway.
1883, Feb. 10: Lewis M. T.	Deveria,	c/o P. M'Intosh & Son, 129 Stockwell Street, Glasgow.
1895, Jan. 22: James A.	Diack,	Bon-Accord, Dumbreck, Glasgow.
1886, Nov. 23: Thomas B.	Dick,	Post Office, Vallejo, California, U.S.A.
1888, Mar. 20: B. B.	Donald,	9 Balgray Ter., Springburn, Glasgow.
1891, Feb. 24: Patrick D.	Donald, B.Sc.,	72A George Street, Edinburgh.
1891, Feb. 24: John	Dougan,	13 Leven Street, Pollokshields, Glasgow.
1884, Jan. 22: William	Dunlop,	6 Chatsworth Terrace, Barrow-in-Furness.
1893, Feb. 21: Turner	Dunn,	20 Park Circus, Glasgow.
1885, Mar. 24: Robert	Elliot, B.Sc.,	59 Houston Road, Forrest Hill, London, S.E.
1880, Dec. 21: Henry M.	Fellows,	76 Southtown Road, Great Yarmouth.
1892, Oct. 25: James M.	Ferguson,	———
1888, Dec. 18: John	Ferguson,	Formans & M'Call, 160 Hope Street, Glasgow.
1895, Jan. 22: Lewis	Ferguson,	Fergus Villa, Paisley.
1895, Jan. 22: Peter	Ferguson, Jr.,	Fergus Villa, Paisley.
1891, Dec. 22: W. L.	Fergusson,	Hawcoat Lane, Abbey Rd., Barrow-in-Furness.
1891, Dec. 22: Alexander	Fergus,	7 Ibrox Place, Glasgow.
1881, Nov. 22: Charles J.	Findlay,	———
1893, Feb. 21: Louis	Findlay,	c/o Mrs Ferguson, 29 Bentinck Street, Glasgow.
1892, Nov. 22: Andrew C.	Fraser,	———

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1886, Apr. 27: J. Imbrie	Fraser,	13 Sandyford Pl., Glasgow.
1894, Dec. 18: Tom J.	Fryer,	24 Claremont St., Glasgow.
1892, Feb. 23: Norman O.	Fulton,	Woodbank, Mount Vernon.
1894, Dec. 18: Chas.F.A.	Fyfe,	48 Rosebank Ter., Glasgow.
1893, Oct. 24: Andrew	Galloway,	49 Prince's Square, Strathbungo, Glasgow.
1889, Apr. 23: Hugh	Gardner,	Minas Schwager, Coronel, Chili.
1895, Mar. 26: Gilbert	Goodwin, Jr.,	20 Carmichael Street, Govan, Glasgow.
1891, Oct. 27: James	Gourlay,	11 Crown Gardens, Dowanhill, Glasgow.
1894, Dec. 18: Wm. A.	Govan,	Thornton Hall.
1884, Feb. 26: Alexander	Gracie,	Willowbank, Yoker.
1889, Feb. 26: J. E.	Harrison,	21 Westminster Ter., G'gow.
1892, Dec. 20: William	Hay,	36 Grove Street, Glasgow.
1883, Feb. 20: David	Henderson,	Cardross Bank Villa, Cardross.
1890, Dec. 23: Wm. G.	Henderson,	1 Radnor Terrace, Glasgow.
1894, Nov. 20: F. W. L.	Hepting,	51 Cathcart Road, Govanhill, Glasgow.
1892, Jan. 26: Wm. M'L.	Homan,	6 Buckingham Buildings, Glasgow.
1891, Dec. 22: George	Howson,	c/o Robson, Lawrence St., Dowanhill, Glasgow.
1895, Jan. 22: Gerard	Hudson,	140 West Princes Street, Glasgow.
1885, Feb. 24: John	Inglis,	Bonnington Brae, Edinburgh.
1894, Nov. 20: Arch. B.	Irvine,	3 Newton Terrace, Glasgow.
1891, Mar. 24: Harold D.	Jackson,	8 Ruthven St., Kelvinside, Glasgow.

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1893, Oct. 24: Alex. J.	Kay,	38 Hill Street, Garnethill, Glasgow.
1886, Nov. 23: Daniel	Kemp,	57 St. Andrew's Road, Pollokshields, Glasgow.
1890, Oct. 28: John	Kemp,	1 Thornwood Ter., Partick, Glasgow.
1890, Oct. 28: Robert G.	Kemp,	2 Ravenscroft Avenue, Connswater, Belfast.
1895, Feb. 26: Irvine	Kempt, Jr.,	Foresthill, Kelvinside, Glasgow.
1893, Apr. 25: Charles A.	King, B.Sc.,	C. C. Lindsay, 167 St. Vincent St., Glasgow.
1891, Oct. 27: James	King,	Carrizal, Bago, Chili.
1886, Jan. 26: John	King,	110 Garthland Drive, Dennistoun, Glasgow.
1894, Feb. 20: David W.	Kinmont,	3 Germiston Street, Glasgow.
1894, Nov. 20: John	Kirk,	4 Minard Terrace, Partickhill, Glasgow.
1890, Oct. 28: John	Kirkwood,	Formans & M'Call, 160 Hope Street, Glasgow.
1893, Feb. 21: Robert	Laing,	Northbank, Partickhill, Glasgow.
1892, Nov. 22: Thomas W.	Lamont,	711 Cathcart Road, Govanhill, Glasgow.
1888, Nov. 20: Charles	Lang,	2 Bellevue Terrace, Cathcart, Glasgow.
1893, Dec. 19: Thomas H.	Lauder,	Parkhead Forge, Glasgow.
1886, Jan. 26: John	Lee,	26 Edinburgh Road, Upper Armley, Leeds.
1886, Dec. 21: Robert	Lee, Jun.,	13 Hamilton Terrace, West Partick, Glasgow.
1891, Dec. 22: Wm. Orr	Leitch, Jun.,	Cruden Railway, Ellon, Aberdeenshire.

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1894, Jan. 23: Alexander	Lennox,	34 Glasgow St., Hillhead, Glasgow.
1892, Dec. 20: John	Leslie,	7 Park Terrace, Govan, Glasgow.
1883, Nov. 21: William R.	Lester,	4 Strathmore Gardens, W., Glasgow.
1885, Mar. 24: Fred.	Lobnitz,	Clarence House, Renfrew.
1893, Jan. 24: Archibald	M'Arthur,	16 India Street, Partick, Glasgow.
1880, Nov. 2: Patrick F.	Maccallum,	Athenæum, Glasgow.
1883, Dec. 18: Peter	M'Coll,	Stewartville Place, Partick, Glasgow.
1883, Dec. 18: John	Macdonald,	6 Rupert Street, Glasgow.
1891, Oct. 27: Henry	MacEwen,	5 Cathkin Terrace, Mount Florida.
1887, Jan. 25: David L.	M'Geachen,	13 Carmichael St., Govan, Glasgow.
1883, Dec. 18: John Bow	M'Gregor,	17 Bell Street, Renfrew.
1895, Jan. 22: George	M'Intosh,	Dunglass Cottage, Bowling.
1895, Jan. 22: John	M'Intosh,	Oak Bank, Bowling.
1881, Oct. 25: James	Mackenzie,	Fulton Engine Wks., Blackston Street, Liverpool.
1883, Jan. 23: Thos. B.	Mackenzie,	342 Duke Street, Glasgow.
1883, Feb. 26: Robert	M'Kinnell,	56 Dundas Street, S.S., Glasgow.
1891, Feb. 24: Wm.	M'Lagan,	11 Pitt Street, Glasgow.
1882, Dec. 19: Peter	M'Lean,	Waverley Ironworks, Galashiels.
1885, Jan. 27: John	M'Millan,	26 Ashton Ter., Glasgow.
1886, Dec. 21: Andrew	M'Vitae,	4 Clutha St., Paisley Road W., Glasgow.
1894, Dec. 18: John	Macintosh,	7 Park Quadrant, Glasgow.
1886, Dec. 21: James	Mack,	3 Germiston Street, Glasgow.

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1894, Nov. 20: Robert D.	Mackintosh,	Bellevue Place, Garngad Hill, Glasgow.
1887, Feb. 22: Cree	Maitland,	Manager, Sunger Ujong Railway, Port Dickson, Malay Peninsula.
1894, Nov. 20: John	Maitland,	53 Bentinck Street, Glasgow.
1894, Mar. 20: John Boyd	Mather,	Kirkhill, Mearns.
1889, Jan. 22: George	Menzies,	26 Minerva Street, Glasgow.
1889, Jan. 22: Robert	Menzies,	Chelmsford Hotel, Tongaat, Natal.
1889, Apr. 23: John	Miller,	813 Govan Road, Govan, Glasgow.
1890, Feb. 25: Robert F.	Miller,	10 Windsor Terrace, West, Glasgow.
1894, Nov. 20: John S.	Millar,	3 Beaconsfield Street, Partick, Glasgow.
1889, Feb. 26: Sidney	Millar,	32 Annette St., Govanhill, Glasgow.
1884, Nov. 25: Thomas	Millar,	Sir W. G. Armstrong, Mitchell, & Co., Ld., Walker Shipyard, Newcastle-on-Tyne.
1883, Dec. 18: Charles W.	Milne,	5 Park Terrace, Langlands Road, Govan, Glasgow.
1881, Jan. 25: Ernest W.	Moir,	c/o S. Pearson & Son, 10 Victoria Street, Westminster, London.
1892, Nov. 22: Hector A.	Mollison,	6 Hillside Gdns., Partickhill, Glasgow.
1882, Feb. 21: C. J.	Morch,	Horten, Norway.
1889, Dec. 17: Arthur M.	Morrison,	Laurel Bank, Partick, Glasgow.
1892, Jan. 26: James H.	Muir,	140 Bath Street, Glasgow.

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1891, Apr. 28: Wm.	Muirhead,	Cloberhill, Maryhill, Glasgow.
1892, Nov. 22: Ernest C.	Mumme,	3 Germiston St., Glasgow.
1893, Feb. 21: Richard	Munro,	———
1892, Oct. 25: John A.	Murdoch,	7 Park Circus Pl., Glasgow.
1893, Oct. 24: B. Stewart	Murphy,	c/o Mr H. Hogarth, 12 Great Clyde Street, Glasgow.
1887, Dec. 20: David	Myles,	Northumberland Engine Works, Wallsend-on-Tyne.
1892, Jan. 26: John S.	Napier,	49 Lilybank Gardens, Hillhead, Glasgow.
1886, Jan. 26: Thomas	Nicholson,	6 Annfield Place, Glasgow.
1895, Mar. 26: John	Orr,	c/o Mrs Reid, Raglan Place, Partick, Glasgow.
1891, Dec. 22: Hugh	Osborne,	30 Rose Street, Garnethill, Glasgow.
1891, Dec. 22: Marshall	Osborne,	87 Cranfield Rd., Brockley, London, S.E.
1888, Jan. 24: James V.	Paterson,	307 Walnut Street, Philadelphia, U.S.A.
1892, Dec. 20: Thomas	Paton,	1 Fairley Street, Govan, Glasgow.
1886, Jan. 26: Samuel	Paxton,	5 Lorne Terrace, Pollokshields, Glasgow.
1887, Nov. 22: James	Peacock,	2 Wilton Mansions, Glasgow.
1891, Jan. 27: Gilbert F.	Pollock,	10 Beechwood Drive, Tollcross, Glasgow.
1887, Apr. 6: John C.	Preston,	Assistant Engineer, Brisbane Board of Water Works, Brisbane, Queensland.
1893, Oct. 24: William S.	Pringle,	64 Dee Street, Aberdeen.

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1885, Jan. 27: James L:	Proudfoot,	Lanemark, New Cumnock.
1887, Oct. 25: David H.	Reid,	Attiquin, Maybole.
1884, Dec. 23: James G.	Reid,	Renfield House, Renfrew.
1884, Feb. 26: Walter	Reid,	118 Ingleby Drive, Glasgow.
1894, Jan. 23: James	Richmond,	13 Sutherland Terrace, Hillhead, Glasgow.
1894, Jan. 23: John H.	Richmond,	259 Renfrew St., Glasgow.
1892, Apr. 26: Walter	Robb,	332 Duke Street, Glasgow.
1886, Oct. 26: Alexander	Robertson,	41 Darnley Street, Pollokshields, Glasgow.
1892, Nov. 22: Andrew R.	Robertson,	8 Park Circus Pl., Glasgow.
1890, Oct. 28: Edward F.	Robertson,	62 High Street, Galashiels.
1887, Dec. 20: Matthew	Robin,	Castle Hill, Hamilton.
1891, Nov. 24: James	Russell,	Belmont, Uddingston.
1891, Dec. 22: James	Russell,	7 Broomhill Terrace, East, Partick, Glasgow.
1887, Apr. 6: Joseph W.	Russell,	Kilblain Engine Works, Greenock.
1888, Jan. 24: John A.	Rudd,	128 Hope Street, Glasgow.
1893, Dec. 19: Herbert C.	Sadler, B.Sc.,	2 Minard Terrace, Partickhill, Glasgow.
1885, Oct. 27: Alexander	Scobie,	Culdees, Partickhill, Glasgow.
1886, Mar. 23: Thomas R.	Seath,	Sunny Oaks, Langbank.
1886, Mar. 23: William Y.	Seath,	Sunny Oaks, Langbank.
1880, Apr. 27: Archibald	Sharp,	13 Fairlawn Grove, Chiswick, London, W.
1882, Oct. 24: John	Sharp,	147 East Milton St., Glasgow.
1894, Apr. 24: John J.	Shaw,	12 Lynedoch Pl., Glasgow.
1892, Dec. 20: Wm. David	Shields,	164 Renfrew St., Garnethill, Glasgow.
1893, Dec. 19: Thomas S.	Shute,	34 Hayburn Cres., Partickhill, Glasgow.

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1892, Dec. 20: David C.	Simpson,	Westburn Place, Whiteinch, Glasgow.
1891, Nov. 24: Alex.	Smith,	5 Matilda Terrace, Strathbungo, Glasgow.
1894, Dec. 18: James A.	Smith,	Union Bank House, Virginia Place, Glasgow.
1892, Dec. 20: James	Smith,	20 Dumbarton Road, Glasgow.
1894, Apr. 24: Charles	Smith,	8 Muirpark Gdns., Partick.
1892, Oct. 25: William	Spalding,	532 St. Vincent St., Glasgow.
1891, Dec. 22: James	Stark,	Summerlea, Thornliebank.
1894, Mar. 20: William B.	Stearns,	Melville Fickens & Coy., 75 Lombard Street, London, E.C.
1892, Jan. 26: James	Steel,	239 St. Vincent St., Glasgow.
1892, Dec. 20: J. M.	Steven,	2 Hampton Court Terrace, Glasgow.
1881, Nov. 22: John A.	Steven,	12 Royal Crescent, Glasgow.
1891, Dec. 22: Clement H.	Stevens,	c/o Blandy Bros. & Co., Las Palmas, Grand Canary.
1894, Nov. 20: Allan	Stevenson,	69 Cadder Street, Pollokshields, E., Glasgow.
1893, Apr. 25: Archibald	Stevenson,	Yloilo, Philippine Islands.
1881, Jan. 25: William	Stevenson,	6 West View, Wallsend-on-Tyne.
1875, Dec. 21: Andrew	Stirling,	Denny & Co., Engine Works, Dumbarton.
1888, Jan. 24: Archd.	Stodart,	Netherton, Newton Mearns.
1895, Feb. 26: Thomas R.	Stove,	5 Craigmore Terrace, Partick, Glasgow.
1889, Mar. 26: J. D.	Strang,	4 Victoria Drive, Crosshill, Glasgow.

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1886, Dec. 21: James R.	Symington,	204 St. Vincent St., Glasgow.
1880, Dec. 21: Stanley	Tatham,	Montrose, Bromley Park, Bromley, Kent.
1882, Nov. 28: William	Taylor,	40 Derby Street, Glasgow.
1891, Mar. 24: Ambrose H.	Thomson,	Surveyors' Department, Court House, Marylebone Lane, London, W.
1894, Nov. 20: James	Thomson,	Bellevue, Clydesdale Street, Hamilton.
1894, Nov. 20: Walter M.	Thomson,	Bellevue, Clydesdale Street, Hamilton.
1884, Dec. 23: William	Thomson,	1 University Gardens Terrace, Glasgow.
1892, Jan. 26: Frederick	Thomson,	110 Hill Street, Garnethill, Glasgow.
1891, Dec. 22: Cecil	Tickle,	131 Elder Park Terrace, Govan, Glasgow.
1885, Oct. 27: Peter	Tod,	C. & H. Crichton & Co., Engineers, Victoria Road, Liverpool.
1891, Oct. 27: Campbell	Turnbull,	18 Blythswood Square, Glasgow.
1892, Mar. 22: James	Turnbull,	South Overdale, Langside, Glasgow.
1891, Oct. 27: W. L.	Turnbull,	18 Blythswood Square, Glasgow.
1894, Nov. 20: John	Walker,	Ferncliffe, Old Cathcart, Glasgow.
1893, Mar. 21: G. Underwood	Walker	204 St. Vincent Street, Glasgow.
1892, Jan. 26: John	Wallace, Jun.,	12 Kelvingrove Street, Glasgow.

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1885, Feb. 24: Charles H.	Wannop,	Barclay, Curle & Co., Finnieston Quay, Glasgow.
1889, Oct. 22: Bruce R.	Warden,	Sandeman & Moncrieff, C.E., Newcastle-on-Tyne.
1881, Mar. 22: Robert	Watson,	1 Glencairn Drive, Pollokshields, Glasgow.
1892, Dec. 20: Harry	Watt,	2 Cambridge Terrace, 259 Albert Rd., Pollokshields, Glasgow.
1880, Apr. 27: Robert D.	Watt,	49 Quinsan Road, Shanghai, China.
1884, Apr. 22: John	Weir,	John Scott & Co., Abden Works, Kinghorn.
1885, Nov. 24: James	Welsh,	3 Princes Gardens, Dowanhill, Glasgow.
1882, Nov. 28: Geo. B.	Wemyss,	175 Comelypark Street, Dennistoun, Glasgow.
1892, Dec. 20: Ernest Wm.	West,	13 Leven St., East Pollokshields, Glasgow.
1883, Dec. 18: John	Whitehead,	33 Hamilton Street, Hoole, Chester.
1890, Mar. 25: C. Basil	Williams,	49 Park Rd., W., Glasgow.
1888, Apr. 24: Alexander	Woodburn,	B.Sc., Assam Bengal Railway, c/o Grindlay & Co., Calcutta.
1893, Dec. 19: William	Wotherspoon,	Blytholm, Douglas Gardens, Uddingston.
1887, Oct. 25: James Brown	Wyllie,	Engineers' Office, Loch Dhu Cottage, Kinlochard, by Aberfoyle.

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Honorary Member.

Professor H. Von	Helmholtz,	Berlin.

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David	Carmichael,	Dundee.
Peter	Denny, LL.D., F.R.S.E.,	Dumbarton.
David	Halley,	Copenhagen.
John	Hastie,	Greenock.
James	M'Ritchie,	Singapore.
Professor James	Scorgie,	Aberdeen.

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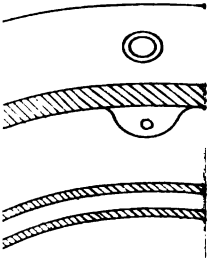

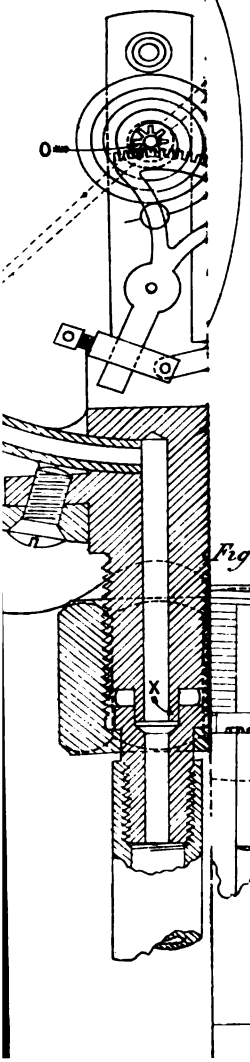

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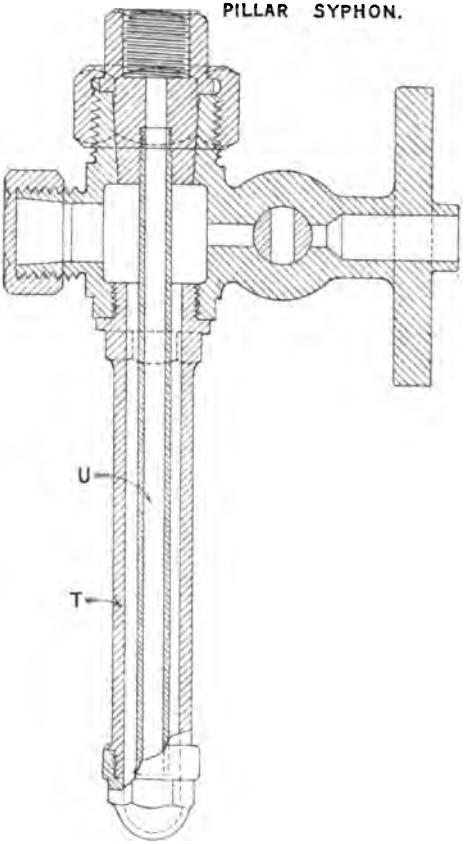

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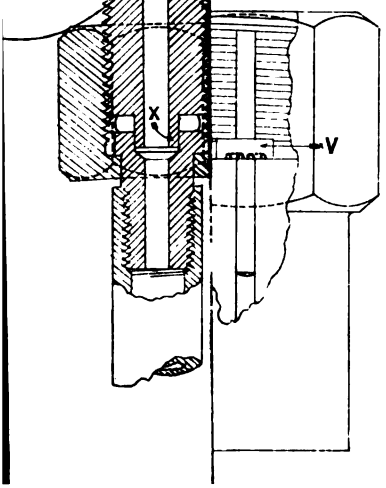

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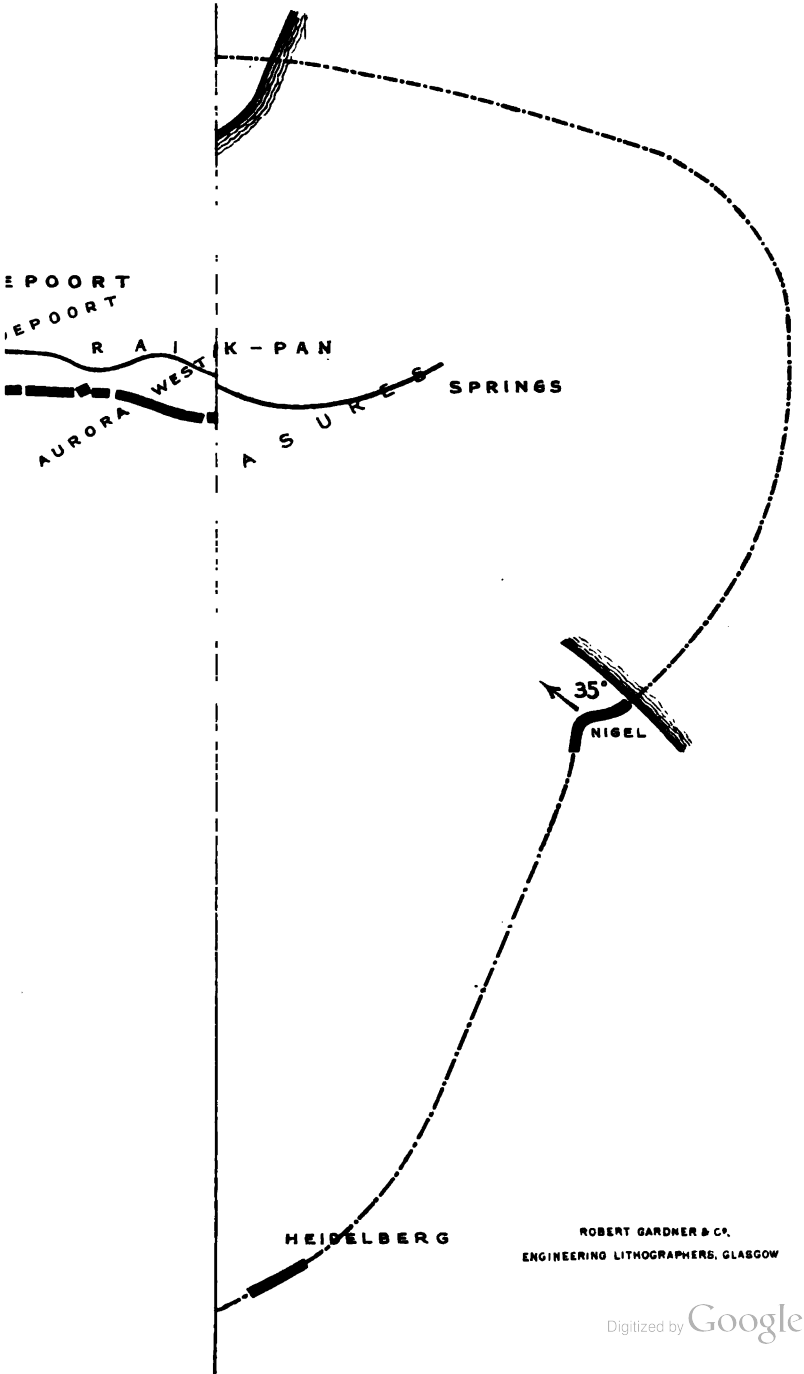

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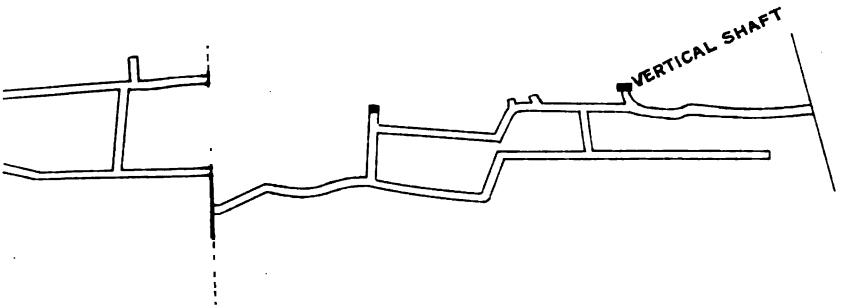

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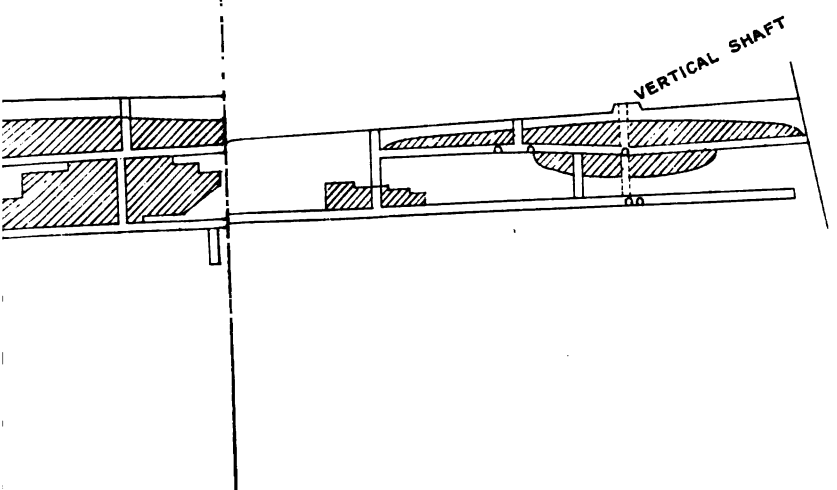

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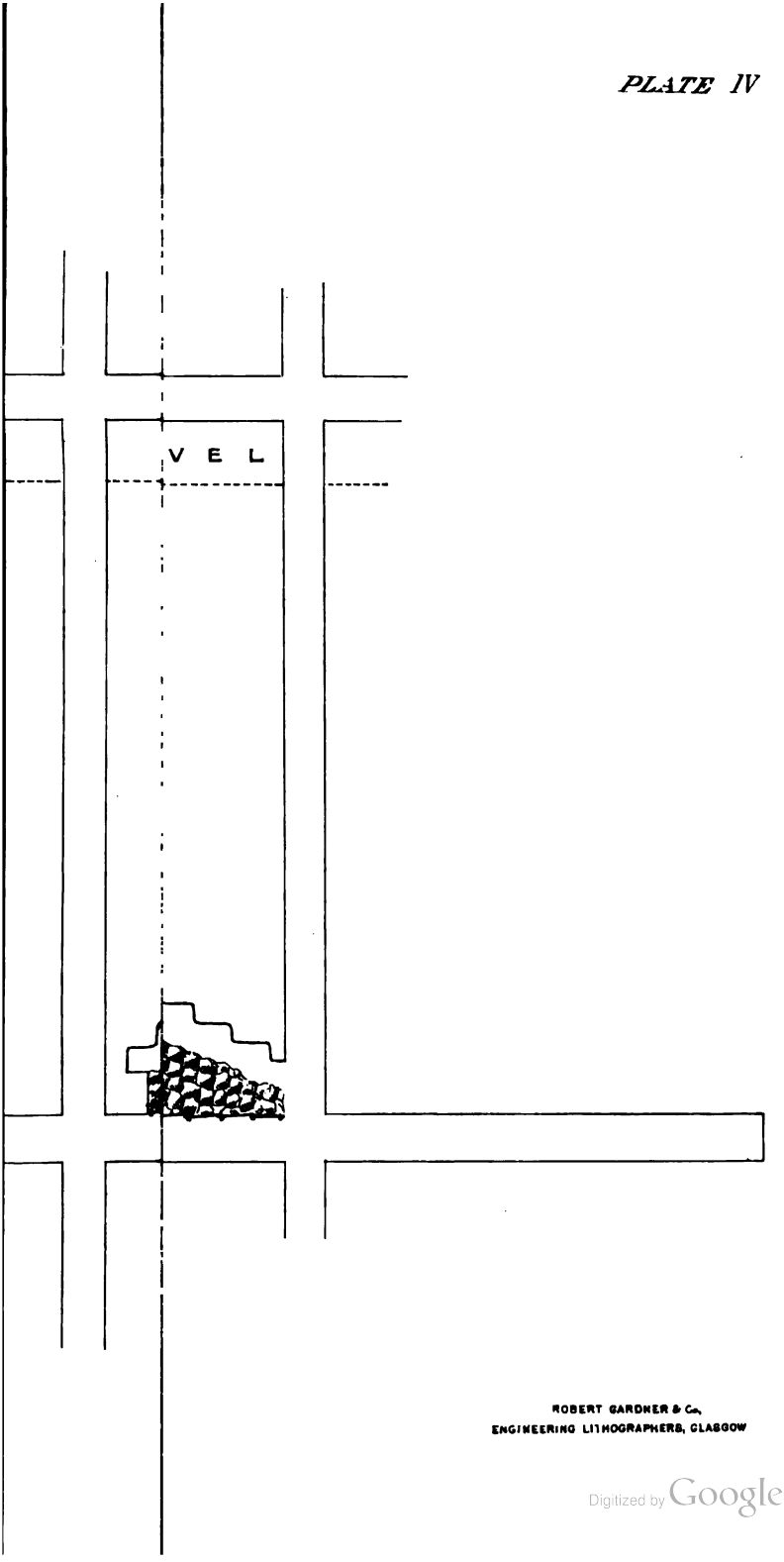

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CROSS SECTION.
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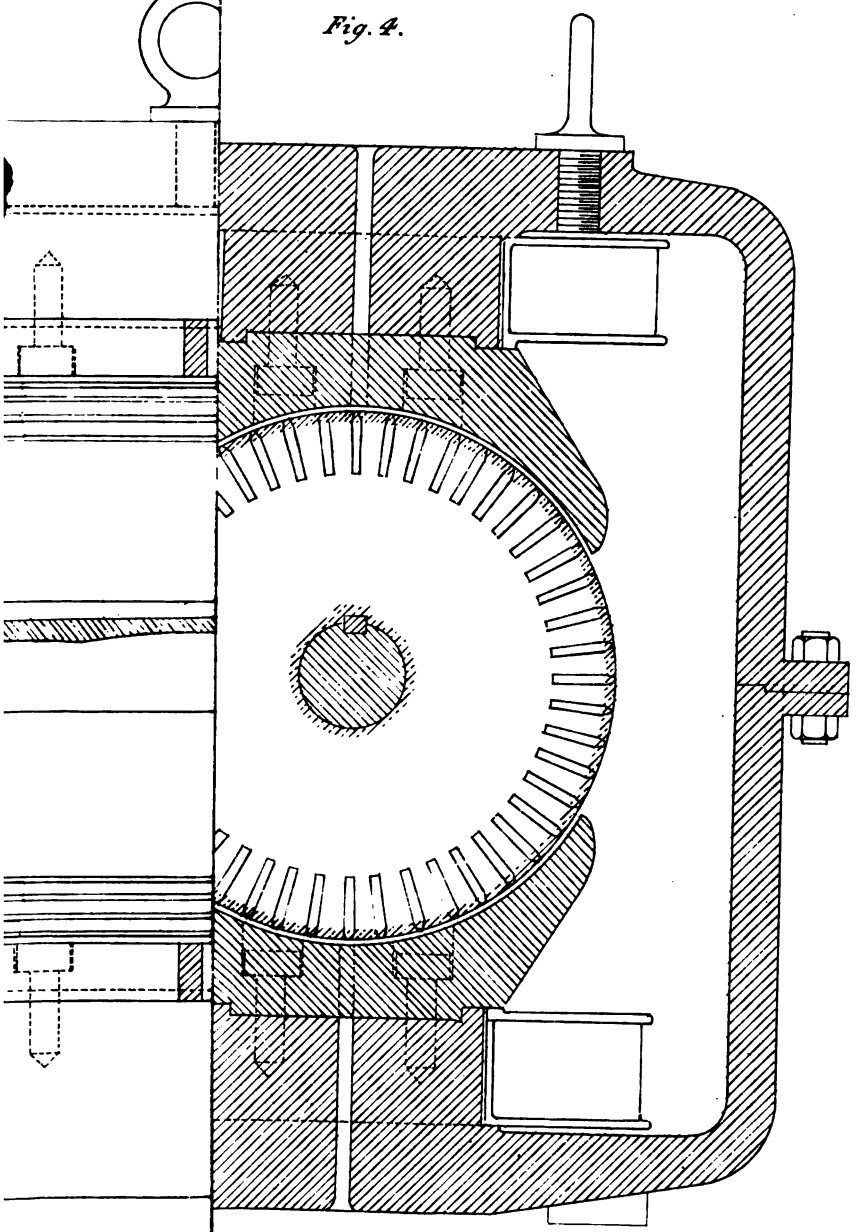
PLATE V

Fig. 4.



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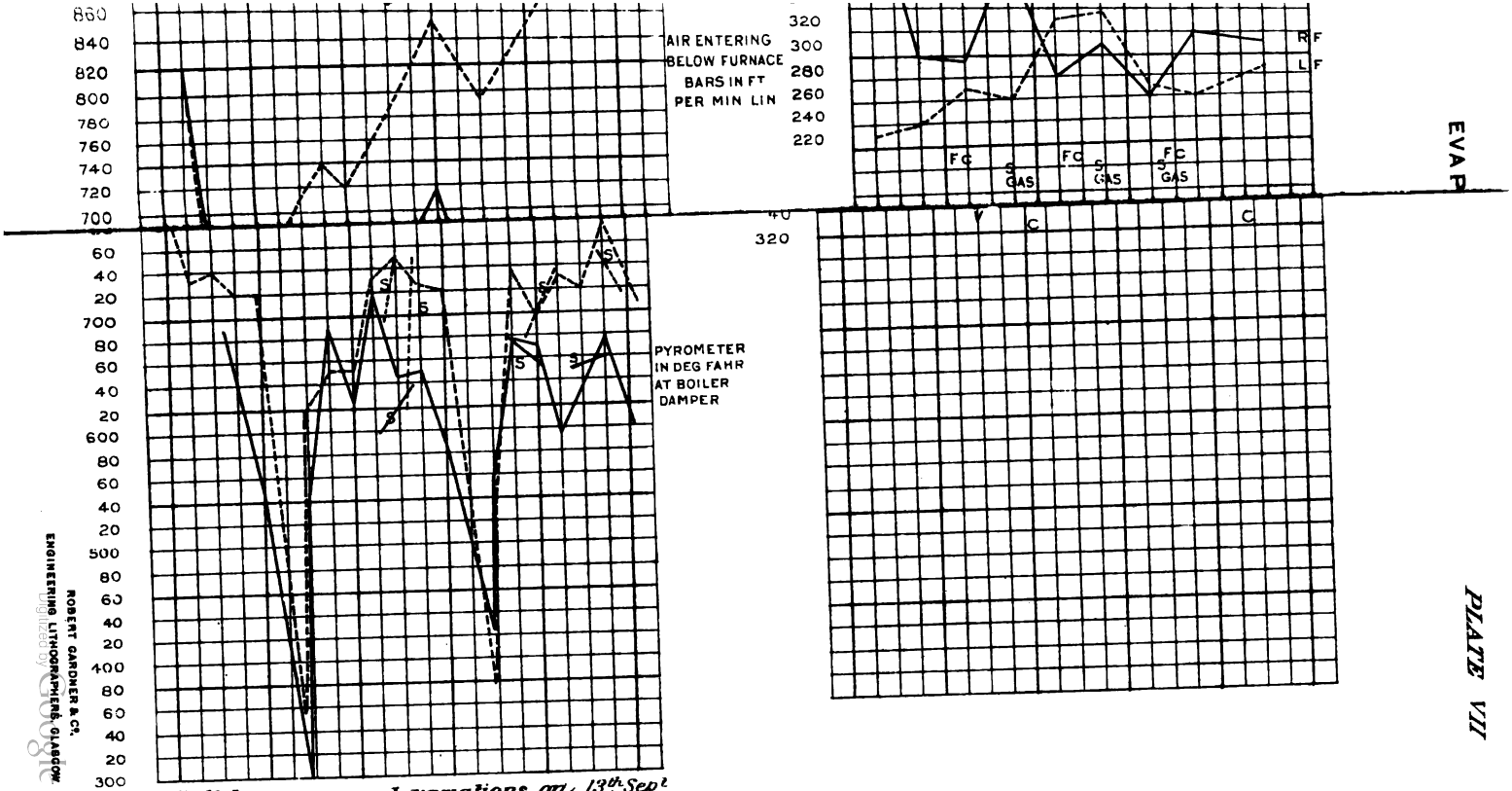
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PLATE VIII

Full lines represent variations on 20th March
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PLATE IX

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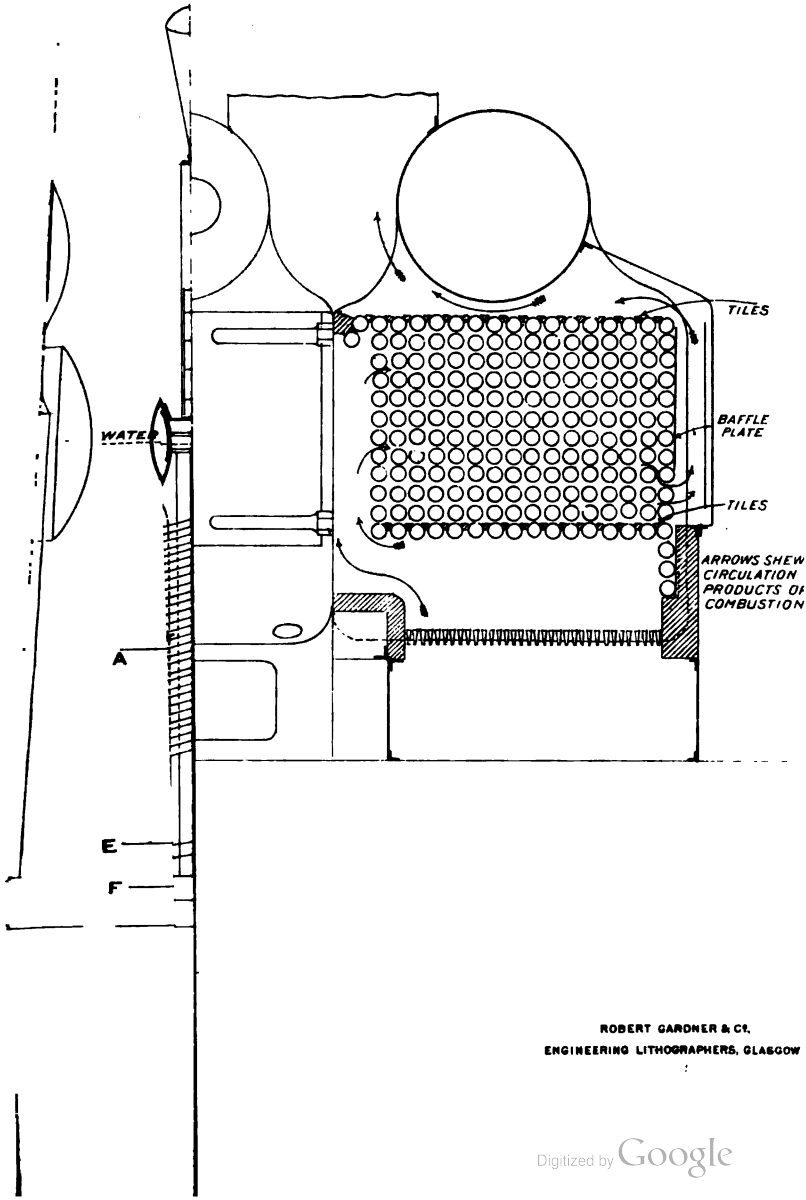

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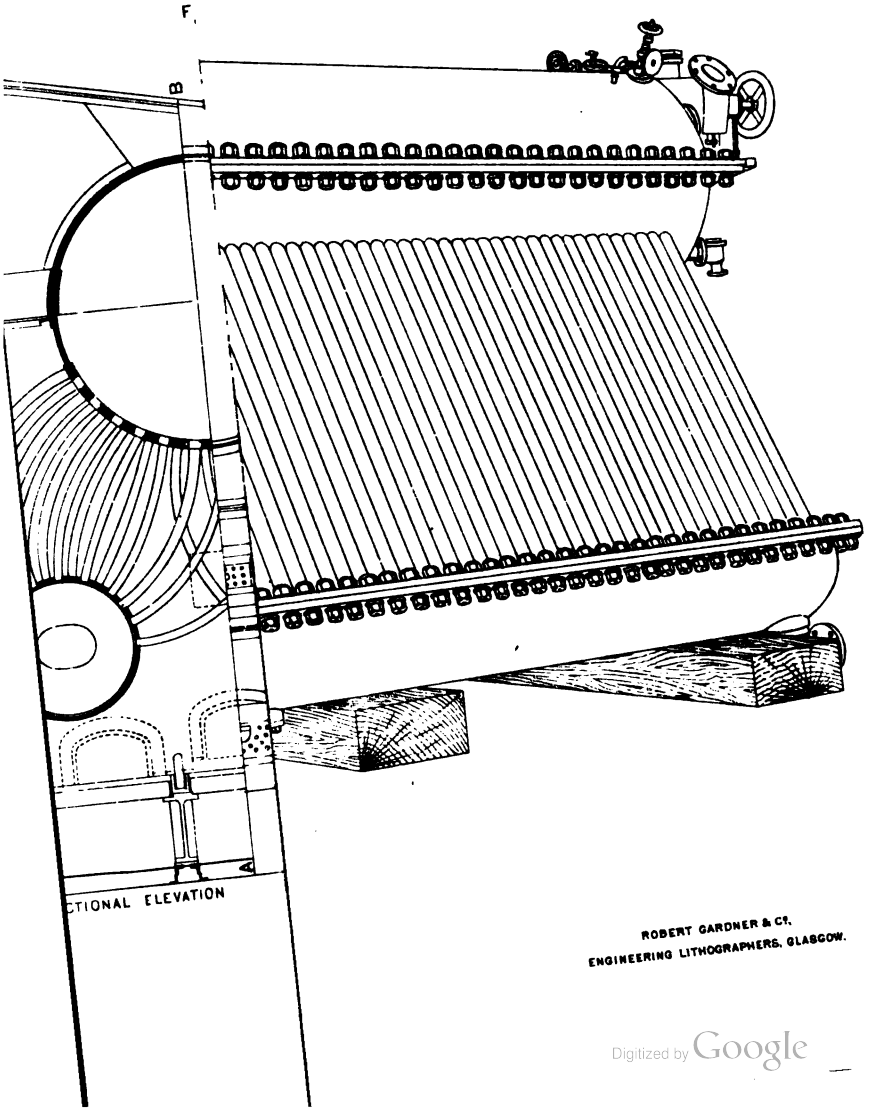
PLATE X

Fig. 6.

YARROW'S BOILER



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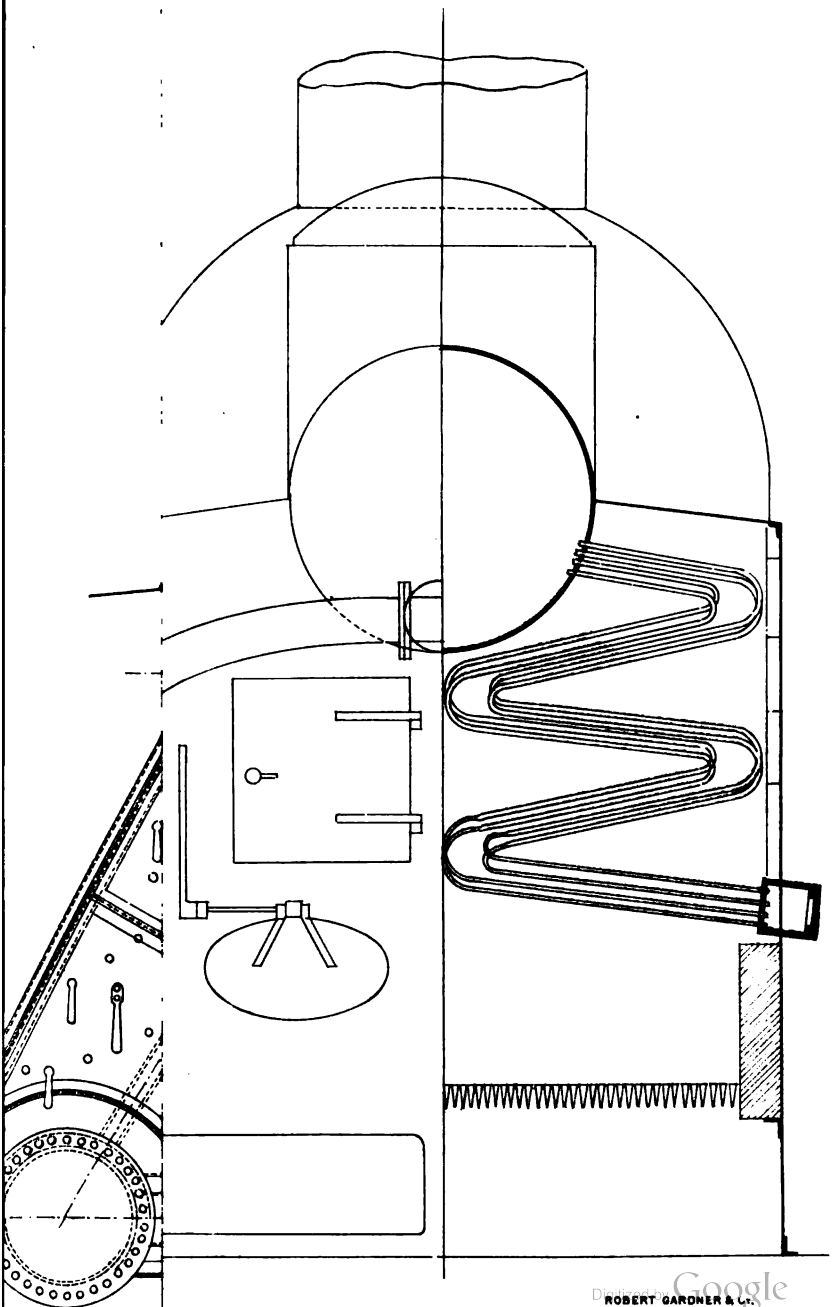

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MES & Cos "CASTLE" DYNAMO.

OLDER FOR CARBON BRUSHES.

LE 1/24
4 86
4 LBS

Fig. 3.

STEEL PLATE 285 REVS

E 1/24
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77 LBS

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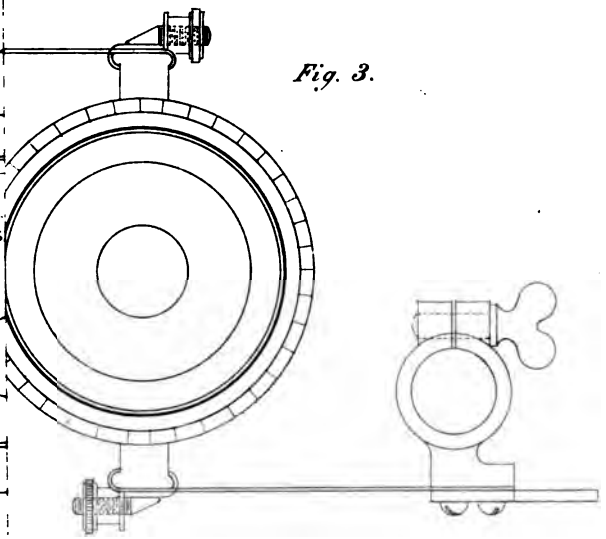
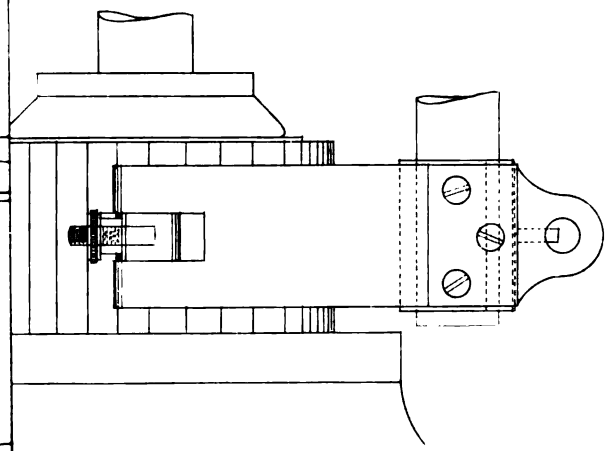
5 16 LBS.

IGHT 84 REVS

ALE 1/24
1 24
5 1 LBS.

14 LBS.





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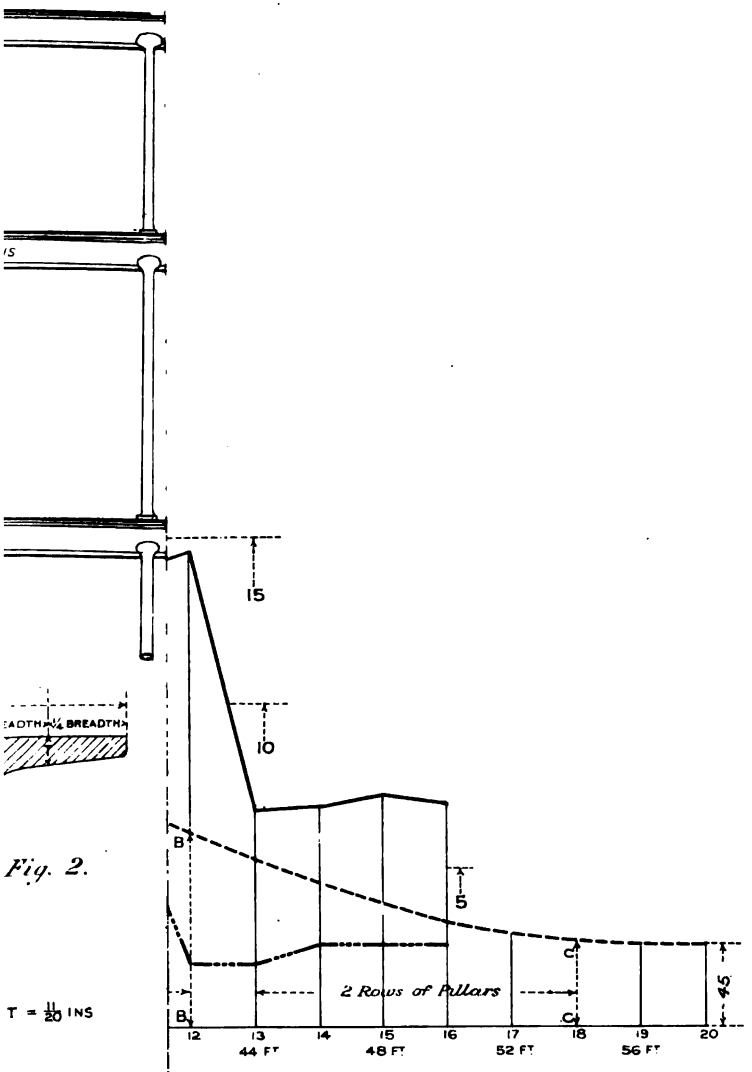

Fig. 2.

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ABLE D

Scantling 4th decks Beams on every frame

3	4	6	7	8	9 L	10 P	11	12
ING MS	DENS OF CA CBC FA	MOMENT OF INERTA	Y	W. TONS PER FT	DISTANCE BETWEEN POINTS OF SUPPORT	STRESS IN BULB TONS PER □ INCH	DEFLECTION IN INCHES	DEFLECTION PER CENT
Tues					Ft Ins			
2	83	16·5	3·52	·247	15-8	13·0	·324	·17
2	81	20·3	3·8	·265	16-7	13·7		
4	7[illegible]	23·9	3·63	·284	17-7	13·1		
11	74	34·4	4·29	·3	18-7	12·8		
6	71	37·6	4·2	·318	19·7	12·5		
6	68	115·1	4·45	·333	20 6	13·9	·469	·19
8	65							
8	62	9·47	2·98	·284	11 9	12·3	·206	·15
8	59	13·5	3·25	·3	12·5	11·1		
8	56	13·5	3·25	·318	13-1	13·1		
8	54	16·5	3·52	·333	13 8	13·3		
0	52	20·3	3·8	·35	14·4	13·4		
		29·9	3·63	·367	15 0	12·5		
18	59	28·4	4·0	·383	15-8	13·3		
18	56	34·4	4·29	·398	16 4	13·0		
8	54	37·6	4·2	·413	17·0	13·3		
7	52	115·1	4·45	·428	17·7	13·1		
7	50	49·3	4·4	·439	18·3	13·1		
7	49	58·8	4·65	·449	18·11	12·7	·353	·16
7	48							
2	117	20·3	3·8	·428	13·2	13·9	·228	·14
4	116	23·9	3·63	·439	13 8	12·5		
4	45	28·4	4·0	·449	14-2	12·8		
6	45	34·4	4·29	·456	14-8	12·1		
5	45	37·6	4·2	·463	15 2	12·0		
7	45	37·6	4·2	·47	15-8	12·9		
7	45	45·1	4·45	·477	16·2	12·4		
7	45	49·3	4·4	·482	16·8	12·0	·297	·15
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Breadth in inches and thicknesses in twentieths of an inch

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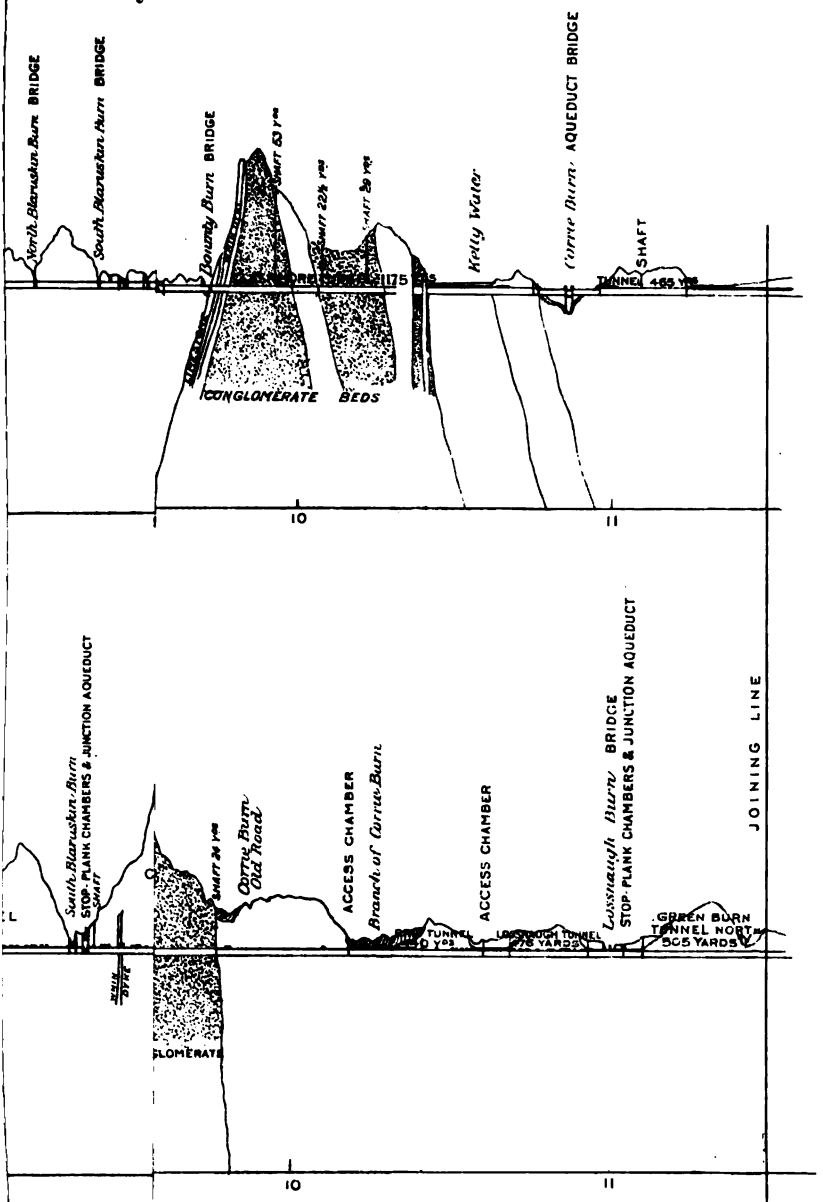

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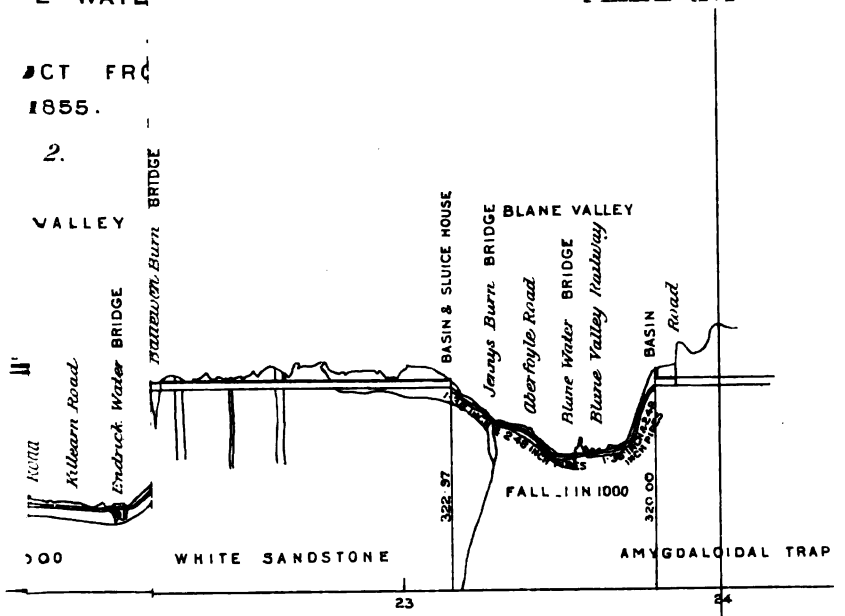
VALLEY

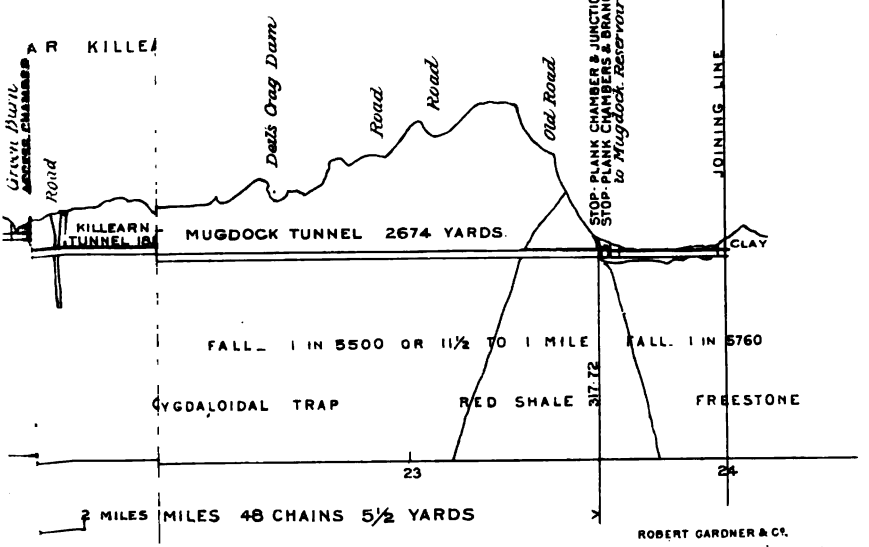
PLATE XVII



UCT FRO

5 & 1892

AR KILLE



2 MILES MILES 48 CHAINS 5½ YARDS

FEET

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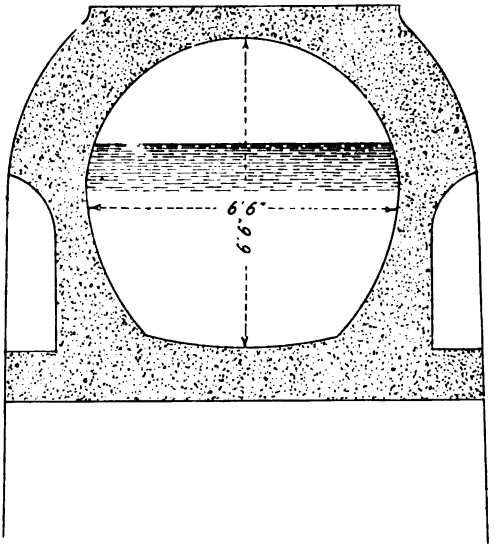
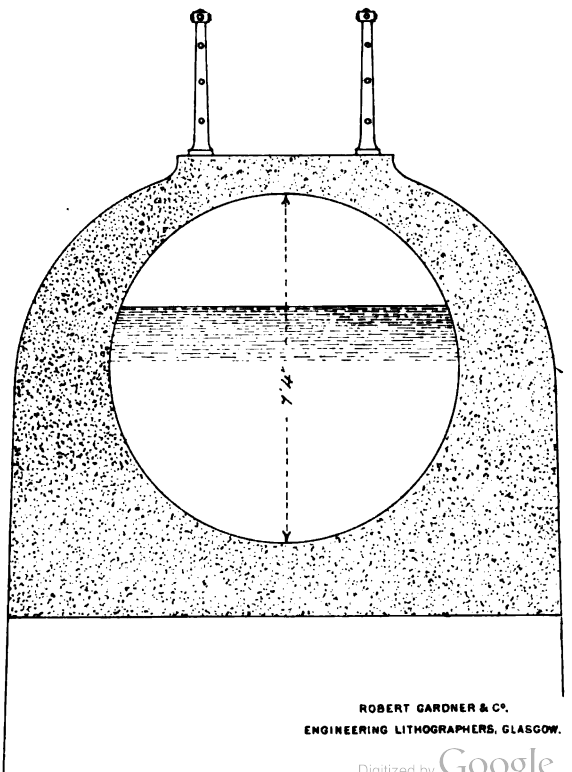
Fig. 3. *PLATE XVIII.*

SECTIONS OF VANNE AQUEDUCT BRIDGES





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Road to Milngavie

H PIPES

BALMORE

HORIZONTAL S
50 60 70 80

VERTICAL SC
200 300

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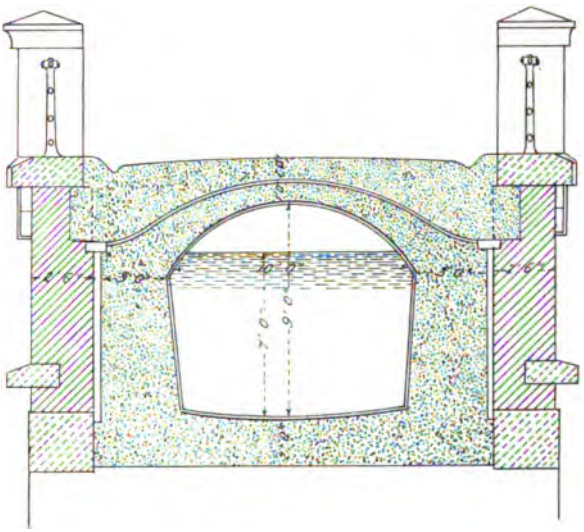
Fig. 9.

NEW AQUEDUCT
DUCHRAY BRIDGE



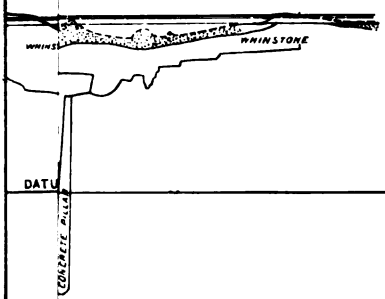


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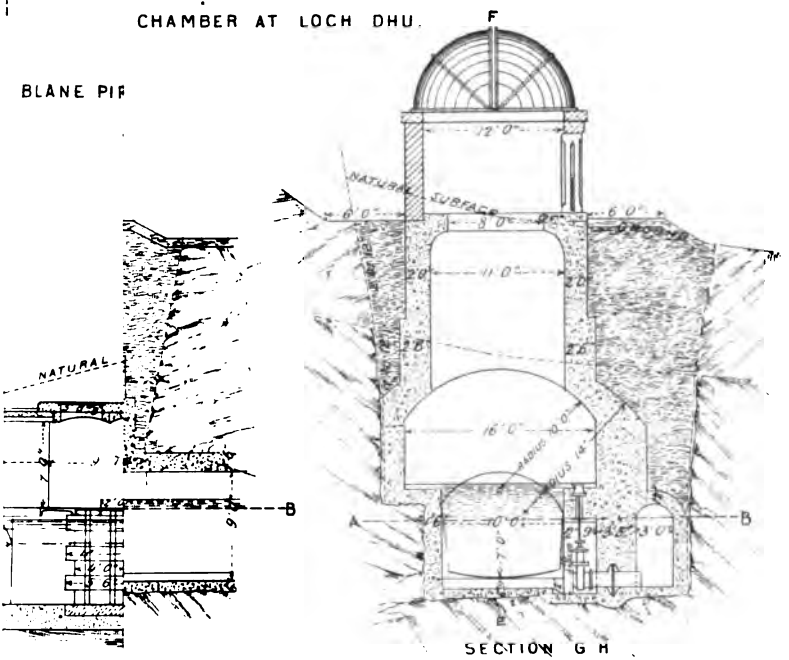
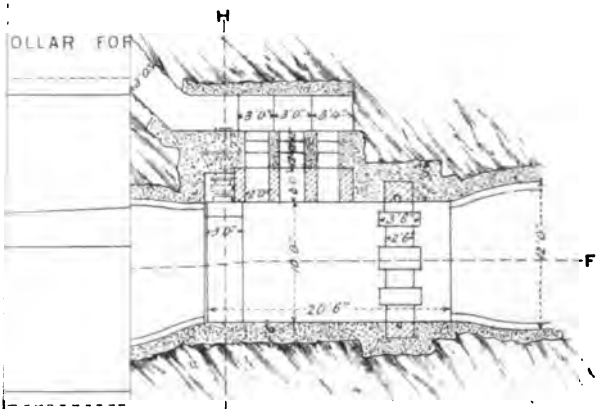
Fig 4.

CHAMBER AT LOCH DHU.

BLANE PIP



SECTION G H



PLAN ON LINE A B

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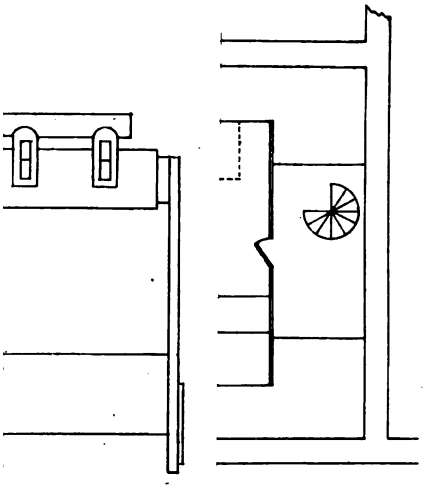

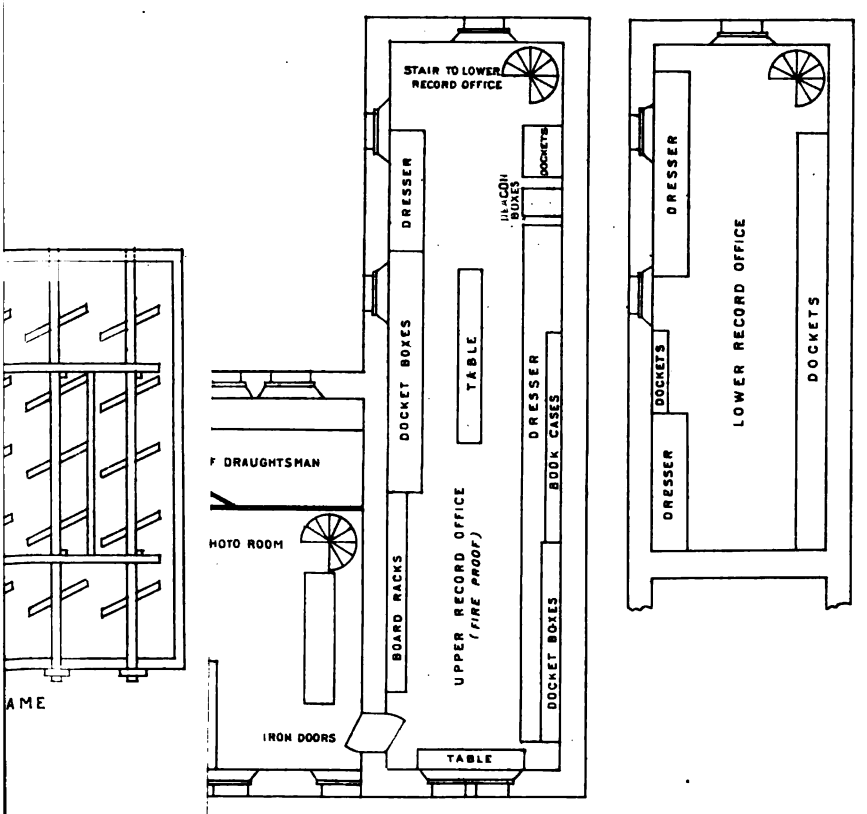

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